



TOOELE  
ARMY  
DEPOT

**DRAFT**

# **GROUNDWATER FLOW AND TRANSPORT MODEL EVALUATION AND DEVELOPMENT**

**TOOELE ARMY DEPOT  
TOOELE, UTAH**

**Contract No. DACW05-00-D-0010  
Task Order No. 7**

Prepared for:



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February 2004

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## ACRONYMS AND ABBREVIATIONS

ft	Feet
ft/day	Feet per day
ft <sup>3</sup> /day	Cubic feet per day
GER	Geology Evaluation Report (URS, 2003)
gpm	Gallons per minute
GUI	Graphical user interface
in/yr	Inch per year
IWL	Industrial Waste Lagoon
µg/L	Microgram per liter
LMG	Link-algebraic multigrid solver
mg/L	Milligrams per liter
MODFLOW 96	USGS MODFLOW model released in 1996
MODFLOW 2000	USGS MODFLOW model released in 2000
MT3DMS	DoD MT3DMS version 3.00 for transport calculations
NEB	Northeast boundary
OIWL	Old Industrial Waste Lagoon
PCG2	Pre-conjugate gradient solver, Version 2
RCRA	Resource Conservation and Recovery Act
RFI	RCRA Facility Investigation
RME	Root mean square error
SWMU	Solid Waste Management Unit
TCE	Trichloroethene
TEAD	Tooele Army Depot
USGS	U.S. Geological Survey
TVD	Total variation diminishing advection
URS	URS Group, Inc.
USACE	U.S. Army Corps of Engineers
USACE-HEC	U.S. Army Corps of Engineers – Hydrologic Engineering Center

## **1.0 INTRODUCTION**

### **1.1 PURPOSE AND SCOPE**

URS Group, Inc. (URS) is contracted by the U.S. Army Corps of Engineers – Sacramento (USACE-Sacramento) to conduct an evaluation and development of the 2003 groundwater and transport models of the Tooele Army Depot (TEAD), in Tooele, Utah. The purpose of this effort is to evaluate the ability of the model to predict the need for future remediation. This work is being conducted under contract DACW05-00-D-0010 Task Order 7: Implementation of Alternative Measures, Industrial Waste Lagoon, Pump and Treat System, Tooele Army Depot, Utah.

The purpose and scope of the model evaluation and model development subtasks are to:

- Review the model structure;
- Assess consistency between the site hydrogeologic data and the model;
- Report groundwater model evaluation results and recommendations;
- Conduct sensitivity analyses.

The data available for this review and analysis included the *Tooele Army Depot Groundwater Flow and Contaminant Transport Model* (USACE-HEC and GeoTrans, 2003; hereafter referred to as the 2003 model report), the TEAD internet database, U.S. Geological Survey (USGS) reports, and the *Draft Comprehensive Geology Evaluation Report* (GER; URS, 2003). Although the scope also includes an assessment of results of the vadose zone modeling conducted during SWMU 58 RFI, that modeling is not yet available and cannot be reported here.

### **1.2 REPORT ORGANIZATION**

The report is organized into the following sections:

- Section 1 – introduces the objectives and scope of this work.
- Section 2 – summarizes the flow and transport model background, approach and results.

- Section 3 – provides a general evaluation of the models and the model report (HEC and GeoTrans, 2003) based on site-specific geology, hydraulic conductivity, water level, and TCE concentration data.
- Section 4 – provides sensitivity analysis results.
- Section 5 – summarizes conclusions of the model evaluation and recommendations for model development.
- Appendices A and B – report on the model review details and report comment details.

The bulk of the interpretation is summarized in accompanying figures and tables within the document.

## **2.0 TOOELE MODEL SUMMARY**

This section provides a brief summary of the contents of the 2003 model report.

### **2.1 HISTORY OF MODELING ANALYSES**

Prior groundwater modeling studies include:

- Two-dimensional and three-dimensional USGS models of the Tooele Valley (Razem and Bartholema, 1980, and Lambert and Stolp (1999)). The more recent study incorporates Tooele pumping data and head observation data (through 1994) and provides information on predicted and observed historical water-level variation throughout the Tooele Valley;
- Three-dimensional USACE-HEC models for TEAD that have evolved and expanded as modeling objectives and available data changed (USACE-HEC, 1993, 1994, 1995, 1998, 2000, 2002; and USACE-HEC and GeoTrans, 2003);
- Hydraulic optimization modeling based on the most recent HEC model (Greenwald, 1999); and
- Flow- and transport-based containment optimization modeling using three alternative optimization codes (Minsker *et al.*, 2003). Cleanup goals were only predicted to be attained through the use of injection as well as extraction.

### **2.2 FLOW MODEL**

The USGS' MODFLOW model (McDonald and Harbaugh, 1988) is used for the flow in the 2003 model. The HEC groundwater flow model consists of a 9-layer model extending laterally to cover both lobes of the TCE plume (i.e., the main and northeast boundary (NEB) plume), and vertically to 1800 feet below the top of the model (which is generally below land surface) into the local bedrock and below the contaminated layers. Zero flow is assumed across the base of the model. The model is divided into about 18,000 cells of 200 by 200 feet (ft), with vertical dimensions ranging from 50 ft (shallow layers) to 200 feet (deepest layer). The model is oriented parallel with the main component of groundwater flow so that inflow from the Oquirrh Mountains and Rush Valley enters the model from the east and south via general-head

boundaries. Outflow to the northwest is also via general-head boundaries, whereas a zero flow boundary exists on the southwestern boundary of the model (parallel with groundwater flow). Minor amounts of inflow (about 1 percent of total inflow) due to precipitation recharge are specified at the modeled water table. Precipitation recharge is assumed to vary over three zones and to be uniform in time. Temporally averaged pumping rates and injection rates, biased toward more recent pumping rates, are supplied to the model for the time period after pumping startup in 1994.

The model is subdivided into 16 zones representing the basement bedrock, various segments of the alluvium that appear to have different hydraulic properties, encapsulation zones around an uplifted bedrock block in the middle of the main TCE plume, and faults or lower-conductivity zones in the alluvium, which are parallel with regional bedrock faulting and identified by observed sudden changes in hydraulic gradient. The hydraulic properties supplied to the model represent average hydraulic conductivities based on the tests that stressed larger portions of the aquifer (i.e., honoring aquifer pumping test results rather than slug tests). During model calibration the hydraulic conductivity zones and the hydraulic conductivities assigned to each zone, as well as the boundary conditions were varied until a good match was obtained with the observed hydraulic heads.

The flow model was calibrated to pre-pumping and post-pumping conditions using inflow rates derived from previous modeling studies (Lambert and Stolp, 1999), and observed drawdowns in the bedrock block due to pumping. The model was run in two steady-state steps (pre- and post-pumping). The resulting model produces a head distribution that is in excellent agreement with the observed heads and in reasonable agreement with the observed drawdowns and boundary inflow rates.

## **2.3 TRANSPORT MODEL**

The widely-used transport model MT3DMS (Zheng and Wang, 1998) was used for the 2003 model. Thirteen sources of known or suspected TCE contamination were simulated in the transport model. The sources are simulated as recharge concentrations, i.e., precipitation recharge is assumed to carry water of a specified TCE concentration to the water table below the source. Sources were assumed to start as early as 1942 when wastewater disposal began at the Industrial Waste Lagoon (IWL), or when the source became active. Many sources were assumed

to continue into the future, except with a drop in IWL source levels in 1988 due to remediation and capping activities that year. Other transport model assumptions include zero decay and very low sorption of TCE, uniform porosity and bulk density, and typical values for dispersivity (a measure of the spreading due to travel through tortuous pathways through soil grains and heterogeneities).

The targets for the transport model calibration were the averaged observed TCE concentrations, and the TCE mass removed by the extraction system through January 2003 (2187 pounds; Kleinfelder, 2002). The observed TCE concentration targets were averaged over 3-year segments between 1988 and the present. TCE source concentrations, porosity and adsorption distribution coefficient (governing partitioning between TCE in the groundwater and TCE adsorbed to the soil) were varied in order to calibrate the model. The model was calibrated based on a visual comparison of predicted and observed TCE plumes. The predicted TCE concentrations decrease with depth, with the water-table layer generally predicted to contain the highest TCE concentrations. Therefore, when viewing the predicted maximum TCE concentrations, some observation points will be over-predicted due to their screen locations below the simulated plume. The predicted TCE plumes generally match observed TCE concentrations, with the exception of main plume wells south of extraction well E-11, and the distal end of the NEB plume which are both under-estimated by the model. However, the predicted TCE mass extracted at the extraction wells is over-predicted by the model. Therefore the best-calibrated model represents a compromise between these two calibration targets.

TCE transport predictions were made for 50 years into the future with and without the extraction/injection system operating. In both cases the TCE sources were conservatively assumed to continue at the concentrations calibrated for 1999 to 2002. If the injection/extraction system continues to operate, the main plume is predicted to be contained and to shrink slightly. If the extraction/injection system is shutdown the main plume edge is predicted to extend slightly beyond the northern TEAD boundary. In both cases, the NEB plume is uncontained and is predicted to expand; doubling in length to the northwest 50 years into the future.

## **2.4 MODEL REPORT**

The model report concludes that the extraction/injection system contains the main plume but not the NEB plume. Fifty years into the future the main TCE plume will, with continued pumping,

retreat slightly and the NEB plume will continue to expand. These model runs use the conservative assumption that all sources remained active at their current levels for the next 50 years. If no future pumping is assumed, the TCE plumes are predicted to expand at a rate of about 100 ft/yr with the 25 micrograms per liter ( $\mu\text{g/L}$ ) TCE contour extending slightly outside the TEAD boundary 50 years into the future. The 2003 model report further concludes that the Building 679 and landfill sources are predominant and that six of the extraction wells provide the most TCE removal. Some of the deeper extraction wells were predicted to capture offsite recharge (i.e., uncontaminated water).

The 2003 model report recommends:

- Additional data gathering as follows: (1) an additional monitoring well near D-2 in the NEB plume to help characterize the nearby fault zone; (2) additional wells at the eastern end of the site (D-series); and (3) source characterization, especially at Building 679, to understand the potential for future decreasing source masses thereby justifying less conservative source assumptions.
- Improvement of the flow model by integration of geophysical and borelog data into the model geologic framework, transient calibration to recovery test data, and addition of more hydraulic conductivity heterogeneity using the transport model results as well as annual water level data updates as guides.
- Improvement of the transport model by assessing preferred transport paths, and application of the transport model to rank the riskiest source areas, and a detailed remedial alternatives comparison (potentially with additional calibration effort).

### **3.0 GENERAL MODEL EVALUATION**

The main emphasis of this review is to assess the model's ability to predict the need or lack of need for future remediation for the TEAD TCE groundwater plume. The method used to evaluate potential future remediation needs is to consider observed and predicted TCE concentrations trends in various parts of the plume. Although this project task is intended to cover model evaluation alone, aspects of model development are also investigated since this seemed to be a more efficient overall approach. The model evaluation took several forms:

- A summary of model weaknesses as were provided in the model report;
- Report and background data evaluation;
- Conversion and importation of TCE and time-varying water-level target data, and running of reported model cases;
- Evaluation of model versus detailed checklist (details provided in Appendix A);
- Running additional model cases for alternate assumptions for TCE sources and transient prediction of water levels; and
- Parameter estimation runs to assess parameter sensitivity, parameter uncertainty, and potential alternate calibrations.

The last item is discussed in the next section; and the remaining items are reported in this section.

#### **3.1 SUMMARY OF REPORTED MODEL WEAKNESSES**

The 2003 model report summarizes weaknesses together with suggestions for improvements. Weaknesses in the flow model are described as:

- Pre-pumping groundwater inflow to the modeled area is 30 percent higher than the estimated inflow target;
- New conceptualization of the bedrock block incorporating geophysics and boring logs are not yet integrated into the model.

Weaknesses in the transport model are described as:

- Under-prediction of TCE concentrations along the center of the northern half of the main plume (i.e., wells south of E-11);
- Under-prediction of TCE concentrations for the distal end of the NEB plume;
- Predicted TCE mass removed by extraction wells (1994 to 2003) is 44 percent higher than actual mass; and
- Potential preferential flowpaths are not yet integrated into the model.

### 3.2 MODEL CONVERSION

The steady-state flow and transient transport models are converted into an alternate graphical user interface (GUI) and the reported cases are rerun and compared with the reported results. The reported results are duplicated in all cases. During model conversion minor differences are found between documented, and electronic files in some parameter values are noted (details are provided in Appendix B).

Also gleaned in the model conversion is that TCE concentration data are averaged over the following observation periods:

Observation Period <sup>1</sup>	Dates (Corresponding Stress Period <sup>2</sup> )	Model Results Year (2003 model figure)
1	March 1982 to June 1987 (stress period 3)	1986 (Figure 29)
2	March 1988 to November 1990 (stress period 4)	1989 (Figure 30)
3	August 1991 to December 1993 (stress period 4)	1992 (Figure 31)
4	January 1997 to December 1999 (stress period 5)	1995 (Figure 32)
5	January 1997 to December 1999 (stress period 5)	1988 (Figure 33 )
6	January 2000 to May 2002 (stress period 5)	2001 (Figure 34)

Notes:

1) An observation period is the period of time over which TCE concentrations were averaged.

2) A stress period is the period of time over which transport boundary conditions were averaged.

The effects of this averaging are investigated and are reported below. The converted model is used in a number of analyses reported in this and the following sections.

### 3.3 GEOLOGY

A draft version of a TEAD-wide geologic evaluation has been provided separately, and the model-related geologic evaluation consisted of comparing the model input data to the geology evaluation results GER (URS, 2003). The cross sections prepared to summarize the bedrock interface data are compared to the corresponding model cross sections. *(Note to reader: the cross sections will change once the USACE revised geology interpretation becomes available.)* The locations of these cross-sections are shown in Figure 3-1 and the comparisons are shown in Figures 3-2 to 3-5. It can be seen that there are many similarities and a few notable differences between the newly-evaluated bedrock data and the model framework. Specifically, in Figures 3-2 and 3-4, the bedrock surface northwest of the bedrock block derived from geophysical surveys is shallower than that modeled. This might help to explain the under-predicted TCE concentrations in this area. Figure 3-4 shows a discrepancy between the observed and predicted water table, and the possible presence of a bedrock trough, in the neighborhood of B-10 and P-10. Figure 3-5 shows a steeper drop in the bedrock surface elevation between C-09 and P-03D than that modeled, and a discrepancy between predicted and observed heads in the vicinity of B-05 and Fault C. Incorporation of the more complex geologic interpretations in the GER may allow for preferred transport paths to be more readily modeled.

### 3.2 HYDRAULIC CONDUCTIVITY

The hydraulic conductivity data used in the 2003 model are “simplified” into 16 zones with faults hypothesized to create hydraulic breaks between adjacent zones around the bedrock block. Given the wide variability in the slug and pump test data results presented in the GER (Appendix A) it is possible that an alternate hydraulic conductivity conceptualization could be envisioned. If hydraulic conductivities are assumed to vary within each zone it is possible that a gradual decrease in hydraulic conductivity adjacent to the bedrock block could explain the observed water level drops there with less reliance on the encapsulation hypothesis. It is not known whether a change to a more heterogeneous hydraulic conductivity distribution would affect any remediation planning, however a potential approach to implementing this in the model is suggested under “Future Modeling Analyses” in Section 5.2. However, in another model familiar to URS a similar encapsulation hypothesis proved to be the most likely explanation of observed water level responses to pumping, so this alternative theory is presented here for primarily completeness rather than as a criticism of the 2003 model.

Calibrated hydraulic conductivities in the model are compared to those values presented in other reports and summarized in the modeling report, and average values summarized in the GER presented in Table 3-1.

**TABLE 3-1**  
**Comparison of Calibrated and Observed Hydraulic Conductivities**

Hydrogeologic Unit	Horizontal Hydraulic Conductivity in feet per day (ft/d)		
	Model-Calibrated Value	Range Reported in 2003 Model Report Section 2.5	Range of Averages Reported in GER Table 5-1
Southern Alluvium	400	150 - 500	14 - 121
Northern Alluvium	200	100 - 300	33 – 299 370 (NEB)
Upper Bedrock	120	20 - 150	-
Lower Bedrock	120	20 - 150	-
Encased Bedrock	80	20 - 150	34 – 179

The calibrated hydraulic conductivity in the southern alluvium is high relative to the observed average values. This may explain the over-estimation of modeled inflows relative to that of the USGS model. Hydraulic conductivity in the northern alluvium in the northeast is low relative to the observed averages. This may partially explain the under-estimation of concentrations in the distal end of the NEB plume. Other calibrated values fall within observed ranges.

### 3.3 WATER LEVELS

The 2003 groundwater flow model is constructed as two steady-state flow steps: pre-pumping conditions, and post-pumping conditions. This section provides a discussion of the potential drawbacks of using steady-state rather than transient flow analyses, and using averaged water-level data as calibration targets, by evaluating water level variations over time.

#### Evaluating the steady-state assumption

The steady-state assumption could be evaluated using actual or simulated pumping test data. For instance, the observed rate of drawdown during long term/wide coverage pumping tests with pumping rates similar to current remediation pumping rates can provide the needed information.

Alternatively, if such information is not available, transient modeling of such pumping tests can provide the needed information.

If such results show rapid drawdown and equilibration over extended periods of time and over large areas, and the results also show that specific yield and storativity are very small, the assumption of steady state is probably valid for the objectives of the model.

On the other hand, if the assumption of steady state flow conditions is not valid, the model may not accurately represent vertical and horizontal capture zones over time, and thus may over- or under-predict the mass of TCE removed from the saturated zone. Another consideration is the degree of confidence in the model calibration. In applying the assumption of steady state flow, calibration of the model cannot fully benefit from the information contained in the transient water levels and concentrations. Including this information in the model and performing transient calibration of water levels would enhance the reliability and credibility of the model results, predictions, and conclusions.

#### Evaluating the transient data

Time-varying water level targets are imported into the model in order to compare predicted and observed water-level time histories. Since the 2003 flow model is constructed in two (pre-pumping and post-pumping) steady-state steps, the model predictions are not expected to mimic observed variations, but the comparison allows the effect of making the steady-state assumption to be assessed. Graphs of simulated and observed water levels are prepared to evaluate how the modeled water levels match observed variations.

Between April 1998 and April 2001 observed water levels recovered then declined. These water level variations probably result not only from pumping rate changes, but also from variations in precipitation recharge in the rest of the Tooele Valley (Lambert and Stolp, 1999). These variations are not simulated or represented in the model but could be incorporated as time-varying boundary conditions. During this period of water level variation, the model assumes pumping continued and capture was maintained, which may not be realistic.

The water level predictions are summarized by region within the model space:

#### **Bedrock Block**

- Very near E-05: the match to currently observed drawdown is reasonable (Figure 3-6).

- Near E-08 and E-05: the match to currently observed drawdown is reasonable inside the block, but poor near the bounding model fault (Figure 3-7).
- Far from E-05, E-08, E-09, E-10, E-04: the match to currently observed drawdown is reasonable inside the block (Figure 3-8).
- Vertical extent of the capture zone may be over predicted because the model simulates less vertical head difference than observed (Figure 3-9).
- Horizontal extent of capture zone inside the block cannot be evaluated because of the paucity of pre-pumping water level data.

### **North of Bedrock Block**

- Near E-02-1/E-02-2: the model under predicts currently observed drawdown by a factor of about two (actual amount is not clear due to lack of pre-pumping data) (Figure 3-10).
- Far from E-02-1/E-02-2, E-13 and E-14: the model generally under predicts drawdown, and a significant period of time during which water levels recovered is not represented. During this period, capture may have been lost, but the model assumes/simulates continual capture (Figure 3-11).
- Near to very near I-2 and I-3: the model simulates the currently observed drawdown reasonably well. However, there is a significant period of time when draw up is observed rather than drawdown (due to injection or shutdown of extraction wells). The predicted zone of influence of injection wells is not accurate, and predicted capture zone of extraction wells are not realistic in this area during the period of draw up (Figure 3-12).
- Far from I-1 and I-2: the model under predicts currently observed drawdown. There is a significant period of time where drawup is observed rather than drawdown (due to injection or shutdown of extraction wells). The predicted zone of influence of injection wells is not accurate, and predicted capture zone of extraction wells are not realistic, in this area during the period of draw up (Figure 3-13).
- Near E-11: the model predicts currently observed water levels, but under predicts drawdown by factor of two. A significant period during which water levels recovered is not simulated (Figure 3-14).

- North edge of plume: Model accurately simulates currently observed water levels, but the predicted drawdown and capture may not be accurate because of the lack of pre-pumping data (Figure 3-15).

In summary, it is found that: (a) water levels have varied significantly over time, probably due both to pumping rate changes and changes in precipitation recharge in the rest of Tooele Valley; and (b) predicted drawdown in the bedrock block is approximated adequately by the model (although in many other checked wells, the drawdown may be off by a factor of two). This conclusion is obscured by other factors likely affecting water levels, such as seasonal variations. While it is reasonable to average observed water levels to filter out seasonal variations in water levels that do not affect the hydraulic gradients, there appear to have been periods when the steady-state capture zones did not apply and the model over-estimates effectiveness of the extraction/injection system.

### **3.4 TCE CONCENTRATIONS**

TCE concentrations in groundwater over time were modeled based on an assumption of the TCE sources. The sources are identified based primarily on TEAD investigative reports within the source area. The model used the following multiple sources for the designated time periods:

- ditches, lagoons, and spreading area (1942 to present);
- Building 679 (1965 on);
- Building 619 (1942 to present); and
- Sanitary landfill (1942 on).

As a contrast, the main plume sources reported in Kleinfelder (2002) were:

- Buildings 600, 604, 607, 611, 614, 615, 619, 620, and 637;
- Suspected burial trench near Building 609;
- The IWL, the Old IWL (OIWL), and wastewater piping; and
- The Sanitary landfill.

Subsequent studies in the Phase I RFI (Parsons, 2003) suggest that the NEB plume sources were:

- The Former Tooele County landfill;

- Building 679;
- Near Building 691; and
- The Bolinder property.

For this evaluation, particle tracking modeling runs are used to assess the potential effects of offsite sources not modeled, i.e., sources at Buildings 600, 620, 611, 637, 691, the Bolinder property and the former Tooele County landfill. The resulting particle tracks from the non-modeled sources, for 61 years of travel with an assumed uniform porosity of 0.2, are shown in Figure 3-16. It can be seen that many of the additional sources are close enough to modeled sources to be indistinguishable in their effect on the plumes. They may however have consequences for focused remedial planning. Moreover, the sources at the Bolinder property and former Tooele County landfill are located in positions that may explain some of the inaccuracy in simulated TCE concentrations in the distal end of the NEB plume.

#### Observed TCE trends

The observed trends in TCE concentrations for selected model wells are summarized in Figure 3-17. This figure shows predicted and observed concentration time histories at source areas, the middle of the main plume, and the distal ends of the main and NEB plumes. The predicted histories are shown as continuous lines with small symbols at each model time saved, and the observed data are shown as individual larger symbols.

The observed TCE concentrations in and close to the modeled source areas generally demonstrate gradual downward trends, suggesting that the source areas are slowly attenuating over time. Since there may be a significant time lag between shallow remediation (such as capping and soil vapor extraction) and a drop in concentration at the water table, it is not surprising that remediation projects have not resulted in significant concentration reduction to date. The observed concentration time histories in the middle of the main plume show significant downward trends throughout. This probably results from remediation both upgradient and downgradient of these locations. The observed concentration time histories at the distal end of the main plume show steady concentrations with variations perhaps corresponding to fluctuations in the operation of the extraction/injection system and/or variations in groundwater inflows. The observed concentration time histories at the distal end of the NEB plume show

mostly downward trends, suggesting that attenuation offsets continuing source releases to this area.

The timing of TCE concentration peaks along the centerline of the main plume is evaluated in order to independently assess the model-assumed hydraulic conductivity values. No consistency in the timing of the peaks is found. This suggests that either there are many time-varying sources or heterogeneous hydraulic conductivities allowing for complex preferential pathways, or both.

#### Modeled TCE trends

The model was calibrated against a series of six TCE plumes over the monitoring duration. Additional analyses were conducted to provide overall remediation statistics, analysis of historical trends, and discussion of the overall three-dimensional nature of the modeled plume. Importation of the TCE concentration targets allowed predicted and observed concentration time histories to be compared. It is found that the averaging procedure used to derive more smoothly-varying concentration trends captured the main features of the original data. Figure 3-18 shows the predicted versus observed TCE concentrations for early 2003. Considering all 106 data points, the residual (difference between predicted and observed concentrations) mean and absolute residual mean are very small, meaning that most data points are matched well at this point in time. In addition, the normalized root mean square error (RME) is 11.7% and the correlation coefficient 0.78, which are excellent statistics. There are only about six wells where significant discrepancies occur and they are geographically scattered and do not cause a bias to the results.

Figures 3-19 and 3-20 show predicted and observed concentration time histories along the centerline of the main and NEB plumes respectively. Trends and differences between predicted and observed concentrations are exaggerated in these figures, which use a linear scale on the y-axis showing TCE concentrations in mg/L. It can be seen that in both the main and NEB plumes observed concentrations are generally trending downward. Predicted concentration trends show downward trends in the main plume and upward trends in the NEB plume. This means that future predictions for the main plume are likely to be more realistic than those for the NEB plume, which may exaggerate the future concentrations at the locations evaluated. There are locations in the NEB plume where TCE concentrations are under-estimated, but these concentrations may potentially be explained by the additional source locations described earlier

and the higher conductivities observed in this area – neither of which is incorporated in the current 2003 model.

The figures of the modeled plume presented in the 2003 model report show maximum concentrations at any depth in two dimensions (i.e., plan view). This provides a worst-case view of the plumes; the predicted plume actually varies in concentrations with depth with the highest concentrations in the layer containing the water table. Three-dimensional views of the plume, from various angles, are shown in Figures 3-21 to 3-24. Each figure shows the simulated bedrock area and injection/extraction well locations (with screened intervals shown in yellow) as well as concentrations in the predicted plume. Figure 3-21 shows the plan view plumes in 2003, looking similar to figures in the model report. The outermost contour in this figure is 5 µg/L. Figures 3-22 to 3-24 show views of the plume from three viewpoints perpendicular to the model boundaries. Figure 3-22 (view from the southwest) shows the predicted plume increasing in depth to the northwest, due to the obstruction of Fault F driving flow and transport downward. Figure 3-23 (view from the northeast) shows the plume bifurcating around the bedrock block and traveling over Fault G, which does not extend to the water table. Figure 3-24 (view from the northwest) shows some extraction and injection wells with screens below the predicted highest concentration layers. It is concluded that the effects of faults on predicted results may be obscured by looking solely at two-dimensional analyses. Complete faults (e.g., Fault F) are predicted to cause vertical spreading of the plume and incomplete faults (e.g., Fault G) are predicted to cause preferential shallow plume migration through the gap in the fault.

### **3.6 SUMMARY**

Model weaknesses reported by USACE-HEC and GeoTrans are summarized and used in interpreting the site background data. Background data evaluation resulted in the following conclusions:

- Incorporation of more complex geologic interpretations (such as presented in the GER) is warranted;
- Hydraulic conductivity values in the Southern Alluvium and northeast Northern alluvium may need to be adjusted;
- Transient water level and flow calculations are warranted;

- Historical capture may be over-estimated at times; and
- Fault assumptions create three dimensional flow paths not obvious in the two-dimensional figures presented in the model report.

A detailed model review checklist was followed. The results are shown in Appendix B. This review resulted in the following assessment:

- The conceptual model and data synthesis in the model are detailed and accurate. The model is obviously based on careful, detailed analyses and extensive calibration.
- The flow and transport models are well calibrated, with the possible exception of the overall model inflows (30 percent greater than that predicted by the USGS model) and the future NEB plume (concentration trends over-predicted in part). This is discussed further in the next section.
- Limited sensitivity analyses were reported. This is discussed further in the next section.
- No verification or uncertainty analysis is performed. However, an independent verification dataset is not available, and uncertainty analyses are traditionally only carried out for high-risk or contentious projects.

Additional model cases were run to assess the transient calibration and additional offsite sources. Particle tracking and transport modeling runs are used to assess the potential effects of offsite sources at the Bolinder property and the former Tooele County landfill. Other potential sources mentioned in recent reports and not included specifically in the model are close enough to modeled sources to be indistinguishable, unless additional site characterization, for example for focused remediation, should provide the data to allow them to be simulated individually.

The report and background data evaluation resulted in corroborating model framework choices and data selection, with the following exceptions: the NEB TCE plume predictions may over-estimate future plume extents because: (a) predicted TCE trends in NEB plume are conservatively high compared to observed concentration time histories, and (b) potential model sources at the Bolinder property and the former Tooele County landfill have not been incorporated into the model.

It is recommended that:

1. The model framework be updated to incorporate the revised bedrock interpretations and some of the hydraulic conductivity data presented in the GER, and to re-evaluate flowpaths versus fault assumptions.
2. The flow model be converted to a transient model with time-varying boundaries taking into account changes in precipitation recharge affecting the rest of Tooele Valley.
3. Model source terms be updated to add (or explain the absence of) the Bolinder property and former Tooele County landfill sources to generate end of NEB plume.
4. The model calibration be updated, in part using the parameter estimation results summarized above, to better match the USGS estimates of model inflows via general-head boundaries, better match the observed drawdowns in the bedrock, and better match the downward TCE concentration trends in the NEB plume
5. Model verification be prepared using the rebound test results.

## **4.0 SENSITIVITY ANALYSES**

This section discusses the results of alternate model runs and sensitivity analyses. The alternate model runs are conducted to assess the effects of historical pumping and alternate future predictions. The purpose of the sensitivity analysis is to rank the input parameters for use in future model calibration and in analyzing prediction uncertainty. The approach used is to apply automated parameter estimation techniques for steady-state (pumping) flow conditions, and transient flow and transport conditions, and to analyze the results in terms of parameter sensitivity, parameter uncertainty, and potential alternate calibrations. Alternate model solvers are used to allow calculations to be made more rapidly. Flow and transport estimations are run separately.

### **4.1 HISTORICAL PUMPING**

Using the existing, calibrated model a case is run in which no historical injections and extraction occurred at TEAD. The results of this case, together with the calibrated model results, are shown in Figure 4-1. This figure shows the maximum concentration predicted in any layer of the model, consistent with the figures presented in the 2003 model report. Looking at Figure 4-1, it can be seen that if no injection and extraction had occurred essentially the same plume size would be predicted for 2003, although the plume mass would have been greater.

### **4.2 FLOW PARAMETERS**

In order to run the parameter estimation cases efficiently, an alternative solver is used. The MODFLOW 96 executable and PCG2 solver were transferred to the MODFLOW 2000 executable and link-algebraic multi-grid (LMG) solver. Convergence criteria are reduced until the mass balance no longer changed with more restrictive convergence, and the mass balance closely approximated that of the original model. Run times are reduced approximately four-fold as a result. Steady state flow calculation and steady state water level targets are used in this analysis; a total of 48 model runs were made. The flow parameter estimation run, with all hydraulic conductivity and infiltration parameters estimated, resulted in ranking the fault hydraulic conductivities as the most sensitive hydraulic conductivity zones, given the observed head data in all the wells (with pumps operating). Infiltration rates are relatively insensitive.

The ranking, from most to least sensitive, is as follows:

1. Fault C horizontal hydraulic conductivity;
2. Far Northern Alluvium horizontal hydraulic conductivity;
3. Fault B vertical hydraulic conductivity;
4. Lower Bedrock horizontal hydraulic conductivity; and
5. Fault A horizontal hydraulic conductivity.

The most sensitive parameters are then used in a steady-state flow parameter estimation analysis to evaluate the possibility of alternate calibrations with observed (pumping) heads and USGS-predicted inflows to the domain as constraints. The 13 most sensitive hydraulic conductivity zones, but not general-head boundary conditions (conductances and heads), were allowed to vary. The sensitivity ranking changed when the inflow constraint is considered in addition to the observed heads:

1. Northern Alluvium (layers 1 to 6) horizontal hydraulic conductivity;
2. Far Northern Alluvium horizontal hydraulic conductivity;
3. Northern Alluvium (layers 7 to 9) horizontal hydraulic conductivity;
4. Fault D horizontal hydraulic conductivity; and
5. Far Northern Alluvium vertical hydraulic conductivity.

Since time-varying heads were not used as a constraint, the parameter-estimated results may not be as accurate an estimate as they could be. The resulting estimated hydraulic conductivity values varied from the original calibration values as presented in Table 4-1.

However, these estimated parameters are also uncertain, indicating that there are insufficient head data in a steady-state analysis to pin down the values uniquely and accurately. Therefore, a transient flow analysis or a combined flow and transport analysis of these parameters would be beneficial. The addition of one or both of these constraints will likely change both the estimated parameter values and the sensitivity ranking. However the change in parameters above indicates that there are alternate calibrations, and, furthermore, suggests variations that could be used either in future trial-and-error calibration or prediction, or future parameter estimation runs.

**TABLE 4-1**  
**Five Flow Parameters that Varied Significantly During Estimation**

Parameter	Model-Calibrated Value (ft/d)	Parameter-Estimated Value (ft/d)
Encased bedrock block horizontal hydraulic conductivity	80	8.1
Fault E vertical hydraulic conductivity	0.01	0.1
Southern Alluvium horizontal hydraulic conductivity	400	187
Lower Bedrock horizontal hydraulic conductivity	120	62
Northern Alluvium horizontal hydraulic conductivity	200	303

The calibration achieved with the new hydraulic conductivity values produces flow in through the general-head boundaries of  $5.03 \times 10^8$  cubic feet per day (ft<sup>3</sup>/day), and the resulting calibration statistics are excellent (less than 5% normalized RME). The predicted head pattern is similar to that presented in the 2003 model report, but with a greater hydraulic gradient across the encased bedrock block. In short, the steady-state flow calibration presented in the model report (HEC and GeoTrans, 2003) is only one possible calibration to this set of data.

## 4.2 TRANSPORT PARAMETERS

Transport sensitivity analyses are carried out using the 13 sources defined in the transport model and two additional sources: the Bolinder property and the former Tooele County landfill. In order to run the parameter estimation cases more efficiently, an alternate solver is used. The MT3DMS total variation diminishing advection (TVD) solver for transport calculations is replaced by the upstream finite difference solver. The mass balances and concentration contours are compared to the original model. The predicted plume showed more lateral dispersion (numerical) than the TVD solver, however, the 5-fold reduction in run time made this approach more tractable to making tens or hundreds of runs for sensitivity analyses. Therefore, the reduced run time approach is used knowing that a final run using the TVD solver is warranted if the parameter estimation approach is used in the future. Transport parameter estimation is carried out using the original, calibrated flow model as a starting point and estimating source terms both for the originally-modeled sources and at the Bolinder property and the former Tooele County landfill. Originally, the full transient observed TCE dataset is used (1,810 observations);

however, the variability in the data prevented a making a satisfactory estimation. Therefore, firstly arithmetically-averaged TCE concentrations were used for each stress period, then geometrically-averaged TCE concentrations over observed periods were used (534 observations). The last approach is found to provide the most realistic results in terms of both statistical matches between predicted and observed concentrations and the 2003 predicted plume. In addition, trials for a couple of different observation weighting schemes were carried out; ultimately uniform weighting was applied to all observations. For these four sets of analyses a total of 199 model runs were carried out. Transient flow and transport calculations are used in this analysis, although the averaged pumping rates used in the original modeling dataset are maintained and only transport parameters are estimated (i.e., water level targets were unused). The TCE plume predicted concentrations are calculated to be most sensitive to:

1. Building 679 source conditions.
2. East Landfill conditions.
3. Ditches A, C, and the OIWL (1942 to 1987, i.e., before and during operation of the IWL).
4. Ditches D, E, IWL, and the OIWL (1988 onward, i.e., post operation of the IWL and during pumping), and the Bolinder property (from 1965 onward). These sources were combined in the estimation process, because they had similar assumed initial estimate concentrations.

The most sensitive sources are also quite well estimated in the calibrated 2003 transport model. When the source terms are re-estimated, most of the source concentrations remained within about 20 percent of the original transport model input data. This suggests that the original transport model is well calibrated. The two sources that did vary significantly are shown in Table 4-2.

Transport sensitivity results imply that the Bolinder property source may contribute significantly to the distal edge of the NEB plume. Also, the most important sources (ranked by mass introduced to the groundwater in the 2003 model report (HEC and GeoTrans, 2003), with the wastewater system ranking highest at early times and building 679 ranking highest at later times) correspond fairly well with the most sensitive sources evaluated by parameter estimation, i.e.,

Building 679 and east sanitary landfill. The resulting calibration statistics are excellent (normalized RMS error of less than 3%; 164 data points, Spring 2003 data).

**TABLE 4-2**

**Two Source Recharge Concentrations that Varied Significantly During Estimation**

<b>Parameter</b>	<b>Model-Calibrated Value (mg/L)</b>	<b>Parameter-Estimated Value (mg/L)</b>	<b>Parameter 95% Confidence Limits (mg/L)</b>
Building 619 source concentration (1942 – 1987)	10	40	20 – 78
East Landfill source concentration (1965 – present)	20	60	50 – 65

Based on the parameter-estimated plume, it is concluded that:

- The NEB plume concentrations are leveling off or slowly decreasing but offsite sources may contribute significantly to the longevity of this plume. This conclusion is different from that presented in the modeling report, which shows the NEB plume expanding significantly in the future. This conclusion could be further investigated by allowing more variation of the Building 679 and Bolinder sources over time to better match the observed trends.
- The main plume is also predicted to be leveling off or slowly decreasing in concentration despite the continuing sources. This implies that the modeled attenuation and extraction more than offset the modeled sources.

### **4.3 FUTURE PREDICTIONS**

The model resulting from the above transport estimation runs is used to assess future plumes with and without injection/extraction pumping. If pumping continues, then several predictions follow. The main plume is predicted to decrease in concentration at its leading edge. This is a similar conclusion to that presented in the 2003 flow and transport model report. The NEB plume is predicted to expand minimally. This is a different conclusion to that presented in the 2003 flow and transport model report, and results from a drop in the assumed Building 679 sources and addition of Bolinder and former Tooele County landfill sources to explain observed

concentrations in the distal portion of the NEB plume. Comparing predicted plumes with and without pumping and injection over the next 50 years:

- There is no difference in the predicted NEB plumes.
- There is very little difference in the predicted main plumes.

#### **4.4 SUMMARY**

Further parameter estimation analyses could be used to:

- Refine the current parameter estimation analyses (check for alternate model calibrations using alternate observation weights and starting conditions);
- Use additional constraints such as extracted TCE mass at the pumping wells and possibly transient head targets;
- Check that use of the TVD solver for transport calculations would not change any conclusions;
- Vary additional uncertain input parameters such as the general-head boundary conductances and the complete suite of transport parameters (Adsorption distribution coefficient and dispersivity were maintained at calibrated levels in the analysis presented here);
- Consider the use of alternate model zonation, such as pilot-point or kriged data to define varying hydraulic conductivities in the alluvium surrounding the bedrock high. This would assess an alternate conceptual model to the fracture zone conductivity discontinuity assumption;
- Apply parameter sensitivity information to focus data collection if additional accuracy is required;
- Apply observation sensitivity information to optimize monitoring network if possible; and
- Apply predictive uncertainty analyses to evaluate the likelihood of future best and worst cases. For example, under future non-pumping conditions assess whether the data and model suggest that offsite concentrations significantly increase or decrease.

## **5.0 CONCLUSIONS**

The main emphasis of this review is to assess the 2003 model's ability to predict the need or lack of need for future remediation for the TEAD TCE plume. Although this project task was intended to cover model evaluation alone, aspects of model development are also investigated since this seemed to be a more efficient overall approach. The model evaluation took several forms: (1) report and background data evaluation, (2) conversion, import of TCE target data, and running of reported model cases, (3) evaluation of model versus detailed checklist, (4) running of additional model cases for alternate assumed TCE sources and transient prediction of drawdowns in the bedrock, and (5) parameter estimation runs to assess parameter sensitivity, parameter uncertainty, and potential alternate calibrations. The model evaluation results are summarized below in terms of the current modeling analysis, recommendations for future modeling analyses, and relevance to remediation planning.

### **5.1 CURRENT MODELING ANALYSIS**

The report and background data evaluation resulted in corroborating model framework choices and data selection, with the following exceptions:

- The NEB TCE plume predictions may over-estimate future plume extents because: (a) predicted TCE trends in the NEB plume were conservatively high compared to observed concentration time histories, and (b) potential model sources at the Bolinder property and the former Tooele County landfill have not been incorporated into the model.
- The calibrated hydraulic properties and plume capture over time may not be accurately represented due to the steady-state flow assumptions (transient water level and flow calculations are warranted).
- Incorporation of more complex geologic interpretations is warranted.
- Hydraulic conductivity values in the Southern Alluvium and northeast Northern alluvium may need to be adjusted.
- Fault assumptions create three dimensional flow paths not obvious in the two-dimensional figures presented in the model report.

The conclusions of the modeling report have been accurately and concisely reported.

The steady-state flow and transient transport models were converted into an alternate GUI and the reported cases are rerun and compared with the reported results. The reported results are duplicated in all cases. The import of the TCE concentration targets allowed predicted and observed concentration time histories to be compared. It is found that: (a) the averaging procedure used to derive more smoothly-varying concentration trends still captured the main features of the original data, (b) the concentration trends in the main plume were difficult to correlate with a single TCE release and probably reflect multiple sources of differing intensities over time, as modeled, and (c) the observed downward-trending TCE concentrations in the NEB plume were not modeled (in fact upward trends were predicted at several locations).

The HEC model is evaluated against a detailed model review checklist, resulting in the following assessment:

- The conceptual model and data synthesis in the model are reasonably detailed and accurate given the objectives of the model. The model is obviously based on careful, detailed analyses and extensive calibration.
- The flow and transport models are well calibrated, with the possible exception of the overall model inflows (30 percent greater than that predicted by the USGS model) and the TCE concentrations in the future NEB plume (concentration trends over-predicted in part).
- Limited sensitivity analyses were reported, and source sensitivity analyses were proposed as future work.
- No verification or uncertainty analysis was performed. However an independent verification dataset was not available, and uncertainty analyses are traditionally only carried out for high-risk or contentious projects.

Additional model cases beyond those in the HEC effort were run to assess the transient calibration and additional offsite sources. It is found that: (a) water levels have varied significantly over time, probably due both to pumping rate changes and changes in precipitation recharge in the rest of Tooele Valley; and (b) predicted drawdowns in the bedrock block are well approximated by the model, but in many other wells checked the drawdowns may be off by a factor of two. This conclusion is obscured by other factors likely affecting water levels.

Particle tracking and transport modeling runs are used to assess the potential effects of offsite sources at the Bolinder property and the former Tooele County landfill. These runs are made using parameter estimation techniques and are discussed in the following paragraph. Other potential sources mentioned in recent reports and not included specifically in the model are proximal to and indistinguishable from the modeled sources.

Parameter estimation runs are made to assess parameter sensitivity, parameter uncertainty, and potential alternate calibrations. Alternate model solvers are used to allow calculations to be made more rapidly. Flow and transport estimations are run separately. The flow parameter estimation run, with all hydraulic conductivity and infiltration parameters estimated, resulted in ranking the fault hydraulic conductivities as the most sensitive hydraulic conductivity zones, given the observed head data in all the wells (with pumps operating). The model is relatively insensitive to infiltration rates.

The most sensitive parameters are then used in a steady-state flow parameter estimation analysis to evaluate the possibility of alternate calibrations with observed (pumping) heads and USGS-predicted inflows to the domain as constraints. The 13 most sensitive hydraulic conductivity zones were allowed to vary, but the general-head boundary condition data (heads and conductances) are kept fixed. The sensitivity ranking changed when the inflow constraint is considered in addition to the observed heads, with the following results:

1. Northern Alluvium (layers 1 to 6) horizontal hydraulic conductivity;
2. Far Northern Alluvium horizontal hydraulic conductivity;
3. Northern Alluvium (layers 7 to 9) horizontal hydraulic conductivity;
4. Fault D horizontal hydraulic conductivity; and
5. Far Northern Alluvium vertical hydraulic conductivity.

The resulting estimated hydraulic conductivity values varied from the original calibration values as summarized in Table 5-1.

**TABLE 5-1****Five Flow Parameters that Varied Significantly During Estimation**

<b>Parameter</b>	<b>Model-Calibrated Value (ft/d)</b>	<b>Parameter-Estimated Value (ft/d)</b>
Encased bedrock block horizontal hydraulic conductivity	80	8.1
Fault E vertical hydraulic conductivity	0.01	0.1
Southern Alluvium horizontal hydraulic conductivity	400	187
Lower Bedrock horizontal hydraulic conductivity	120	62
Northern Alluvium horizontal hydraulic conductivity	200	303

However, these estimated parameters are also uncertain, indicating that there are insufficient head data in the steady-state analysis to uniquely and accurately constrain the parameter values. History matching in conjunction with a transient flow model or a combined flow and transport analysis would help to provide improved estimates of these parameters. The resulting calibration statistics are excellent (less than 5% normalized RME) indicating that alternate model calibrations, including this which honors the USGS-modeled inflow rate, exist.

Transport parameter estimation is carried out using the original, HEC-calibrated flow model as a starting point and estimating source terms both for the originally modeled sources and for sources at the Bolinder property and the former Tooele County landfill. The alternative calibrated flow model is not used in this analysis because it is likely that the flow model parameters will vary again as transient conditions are considered. Transient flow and transport calculations were used in this analysis. The TCE plume predicted concentrations are most sensitive to:

1. Building 679 sources
2. East Landfill sources
3. Ditches A and C, and the OIWL (1942 to 1987)
4. Ditches D, E, IWL, and OIWL (from 1988 on) and the Bolinder property (from 1965 on).

However, the most sensitive sources are also quite well estimated in the calibrated transport model. When the source terms are re-estimated, most of the source concentrations remained within about 20 % of the original transport model input data. The two sources that vary significantly are shown in Table 5-2.

**TABLE 5-2**

**Two Source Recharge Concentrations that Varied Significantly During Estimation**

<b>Parameter</b>	<b>Model-Calibrated Value (mg/L)</b>	<b>Parameter-Estimated Value (mg/L)</b>	<b>Parameter 95% Confidence Limits (mg/L)</b>
Building 619 source concentration (1942 – 1987) and Bolinder property source concentration (1965 on)	10	40	20 - 78
East Landfill source concentration (1965 – present)	20	60	50 - 65

These results imply that the Bolinder property source may contribute significantly to the distal edge of the NEB plume. Also, the most important sources (ranked by mass introduced to the groundwater in the model report (HEC and GeoTrans, 2003), with the wastewater system ranking highest at early times and Building 679 ranking highest at later times) do correspond fairly well with the most sensitive sources evaluated by parameter estimation: (1) Building 679 and (2) East Landfill. The resulting calibration statistics are excellent (normalized RMS error of less than 3%). Based on the parameter-estimated plume, it is concluded that:

- The NEB plume concentrations are leveling off or slowly decreasing, but offsite sources may contribute significantly to the longevity of this plume. This conclusion is different from that presented in the modeling report, which shows the NEB plume expanding significantly in the future. This conclusion could be further investigated by allowing more variation of the Building 679 and Bolinder sources over time to better match the observed trends.
- The main plume is also predicted to be leveling off or slowly decreasing in concentration despite the continuing sources. This implies that that the modeled attenuation and extraction more than offset the modeled sources.

## 5.2 FUTURE MODELING ANALYSES

It is understood that model updates have occurred since the model report (HEC and GeoTrans, 2003) was issued and some of the recommendations provided below may consequently need adjustment. It is further understood that there will necessarily be a compromise between model accuracy and future model effort, but it is recommended that future modeling analyses consider the following options:

1. Update the model framework to incorporate the revised bedrock interpretations and some of the hydraulic conductivity data presented in the GER, and to re-evaluate flowpaths versus fault assumptions
2. Update the model calibration, in part using the parameter estimation results summarized above, to better match the USGS estimates of model inflows via general-head boundaries, and better match the downward TCE concentration trends in the NEB plume.
3. Undertake transient flow model calibration to allow better estimates of extraction and capture over time and allow a better estimate of the effects of the rebound test.
4. Update model source terms to add (or explain the absence of) the Bolinder property and former Tooele County landfill sources to generate the distal region of the NEB plume.
5. Conduct model verification study using the rebound test data when they become available
6. Additional parameter estimation analyses could be used to:
  - Refine the current parameter estimation analyses (check for alternate model calibrations using alternate observation weights and starting conditions),
  - Use additional constraints such as extracted TCE mass at the pumping wells and possibly transient head targets,
  - Check that use of the TVD solver for transport calculations does not change any conclusions,
  - Vary additional uncertain input parameters such as the general-head boundary conductances (and general-head boundary heads if uncertain based on the larger-scale USGS model) and the complete suite of transport parameters (Adsorption distribution coefficient and dispersivity were maintained at calibrated levels in the analysis presented here).

- Consider the use of alternate model zonation, such as pilot-point data to generate (kriged) varying hydraulic conductivities in the alluvium surrounding the bedrock high. This would assess an alternate conceptual model to the fracture zone conductivity discontinuity assumption and make use of the individual pump test and slug test results.
- Apply parameter sensitivity information to focus data collection, if additional accuracy is required
- Apply parameter sensitivity information to focus remediation efforts, if required
- Apply observation sensitivity information to optimize the monitoring network if possible.
- Apply predictive uncertainty analyses to evaluate the likelihood of future best and worst cases. For example, under future non-pumping conditions assess whether the data and model suggest that offsite concentrations significantly increase or decrease, allowing the need for continued pumping to be reassessed.

### **5.3 REMEDIATION**

The model report (HEC and GeoTrans, 2003) concludes that 50 years into the future the main TCE plume will, with continued pumping, retreat slightly and the NEB plume will expand. These runs used the conservative assumption that all sources remained active at their current levels for the next 50 years. If no future pumping is assumed the TCE plumes are predicted to expand at a rate of about 100 ft/yr with the 25 µg/L TCE contour extending slightly outside the TEAD boundary 50 years into the future. It is further concluded that the Building 679 and Sanitary Landfill sources are predominant and that six of the extraction wells provide the most TCE mass removal.

Model evaluation and additional runs presented in this report result in the following additional conclusions about remediation:

- Using the calibrated model provided, and assuming that the inherent assumptions, such as steady flow conditions, are applicable:
  - The injection and extraction to date has effectively kept pace with the modeled sources over the last 10 years.

- If no injection and extraction had occurred essentially the same plume size would be predicted for 2003, although the plume mass would have been greater. This implies that, based on the current HEC model, historical pumping has not produced significant offsite risk reduction.
- Using the model with recalibrated sources:
  - The main plume is predicted to decrease in concentration at its leading edge. This is a similar conclusion to that presented in the flow and transport model report (HEC and GeoTrans, 2003).
  - The NEB plume is predicted to expand minimally. This is a different conclusion to that presented in the flow and transport model report. The difference in conclusions results from a drop in the assumed Building 679 sources and addition of Bolinder and former Tooele County landfill sources to explain observed concentrations in the distal portion of the NEB plume.
  - Comparing predicted plumes with and without pumping and injection over the next 50 years:
    - there is no difference in the predicted NEB plumes, and
    - there is very little difference in the predicted main plumes

This means that alternate model calibrations may (and in this case do) lead to different conclusions about the need for future remediation and therefore further modeling analyses are warranted and worthwhile.

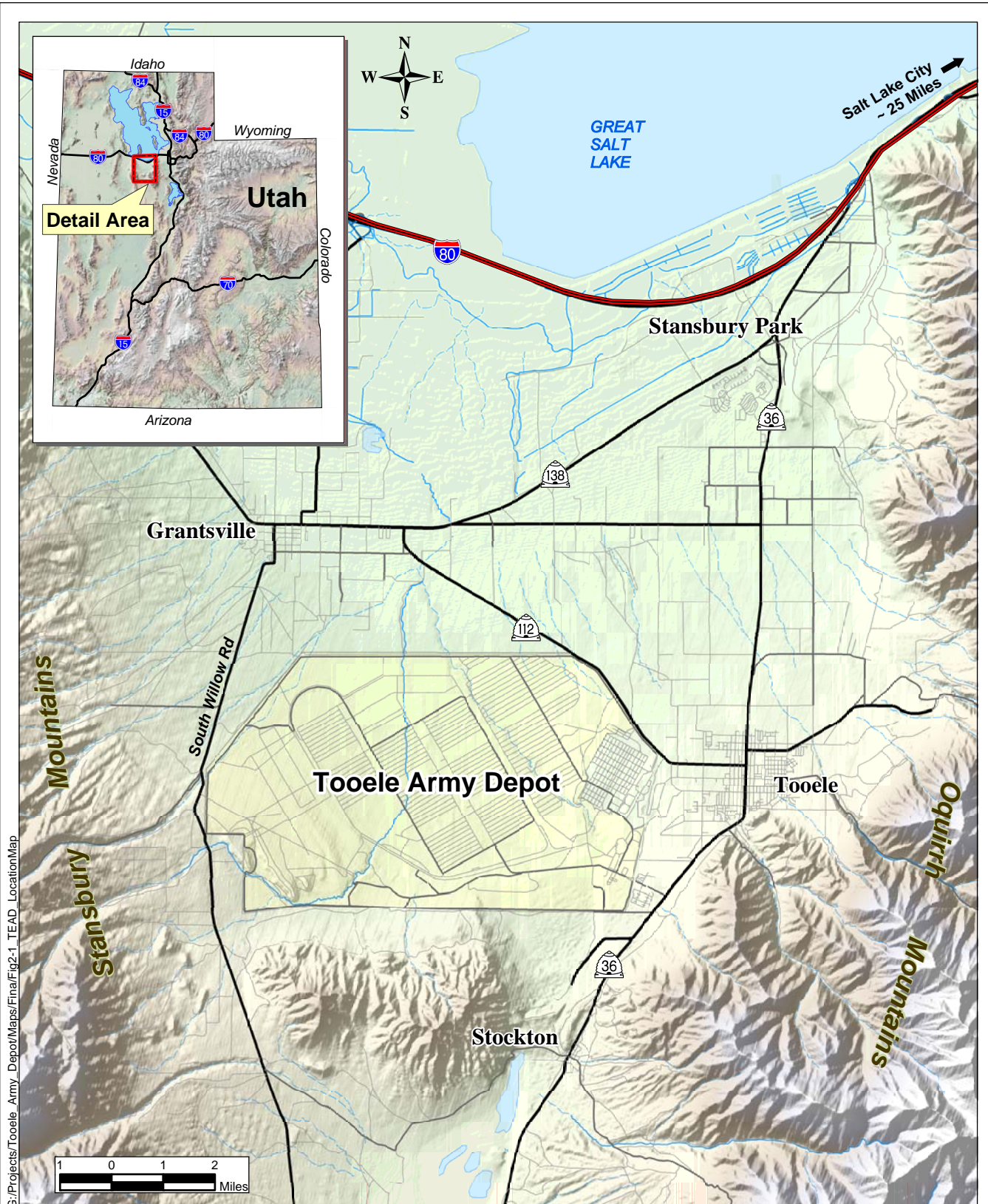
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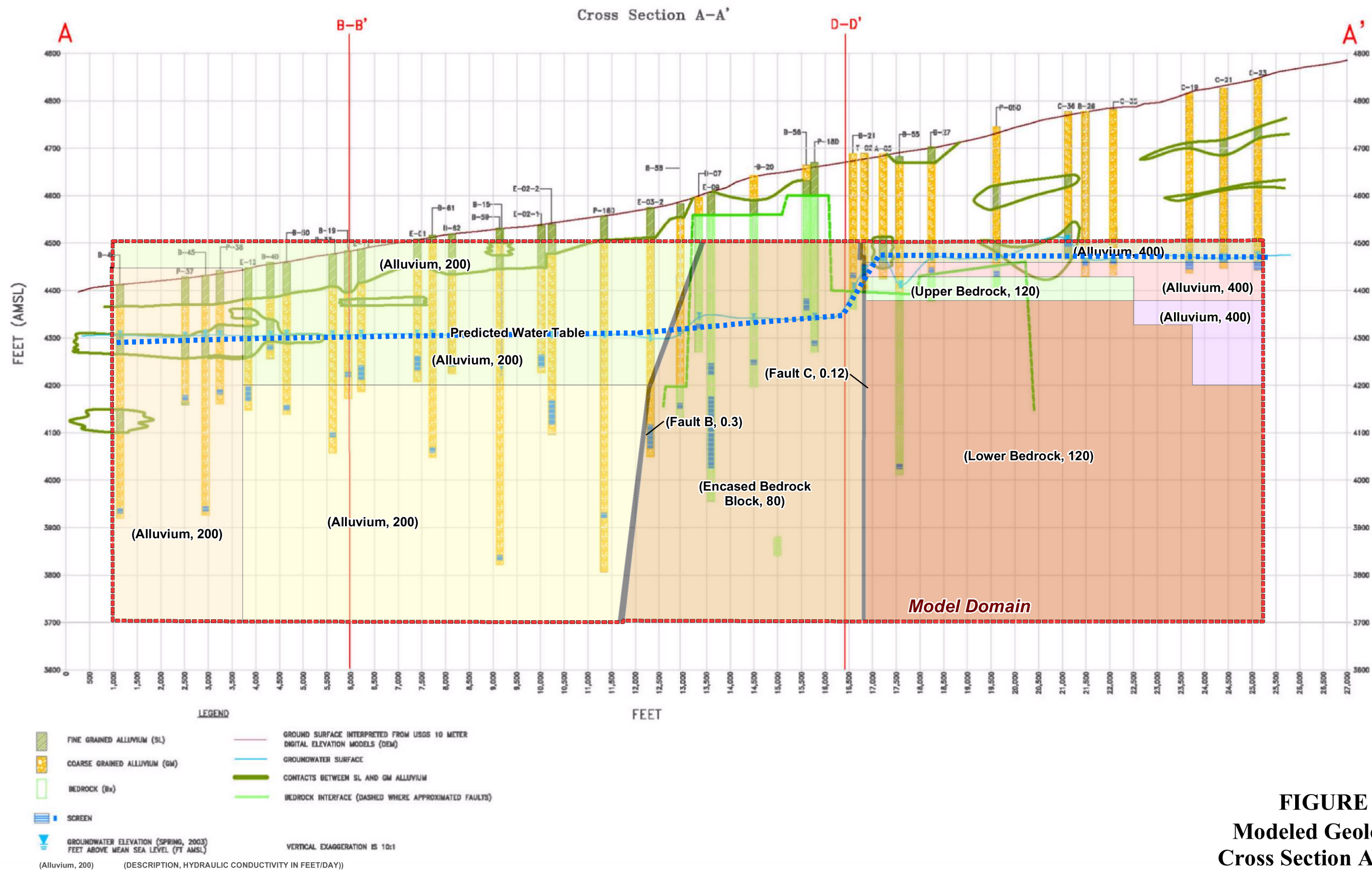
## FIGURES



G:\Projects\Tooele Army Depot\Maps\Final\Fig2-1 TEAD LocationMap

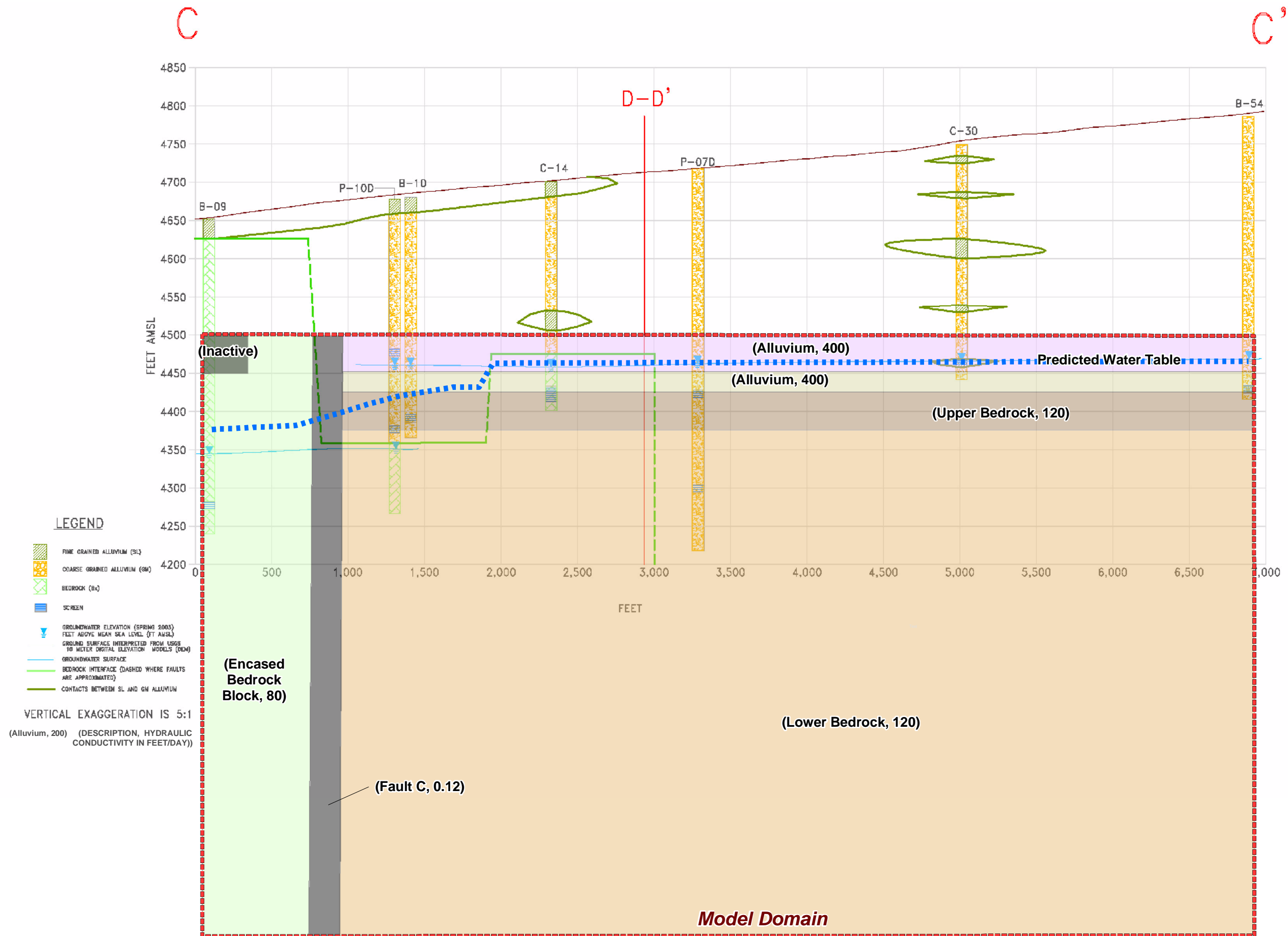
**FIGURE 2-1  
Tooele  
Location Map**





**FIGURE 3-2**  
**Modeled Geology**  
**Cross Section A-A'**

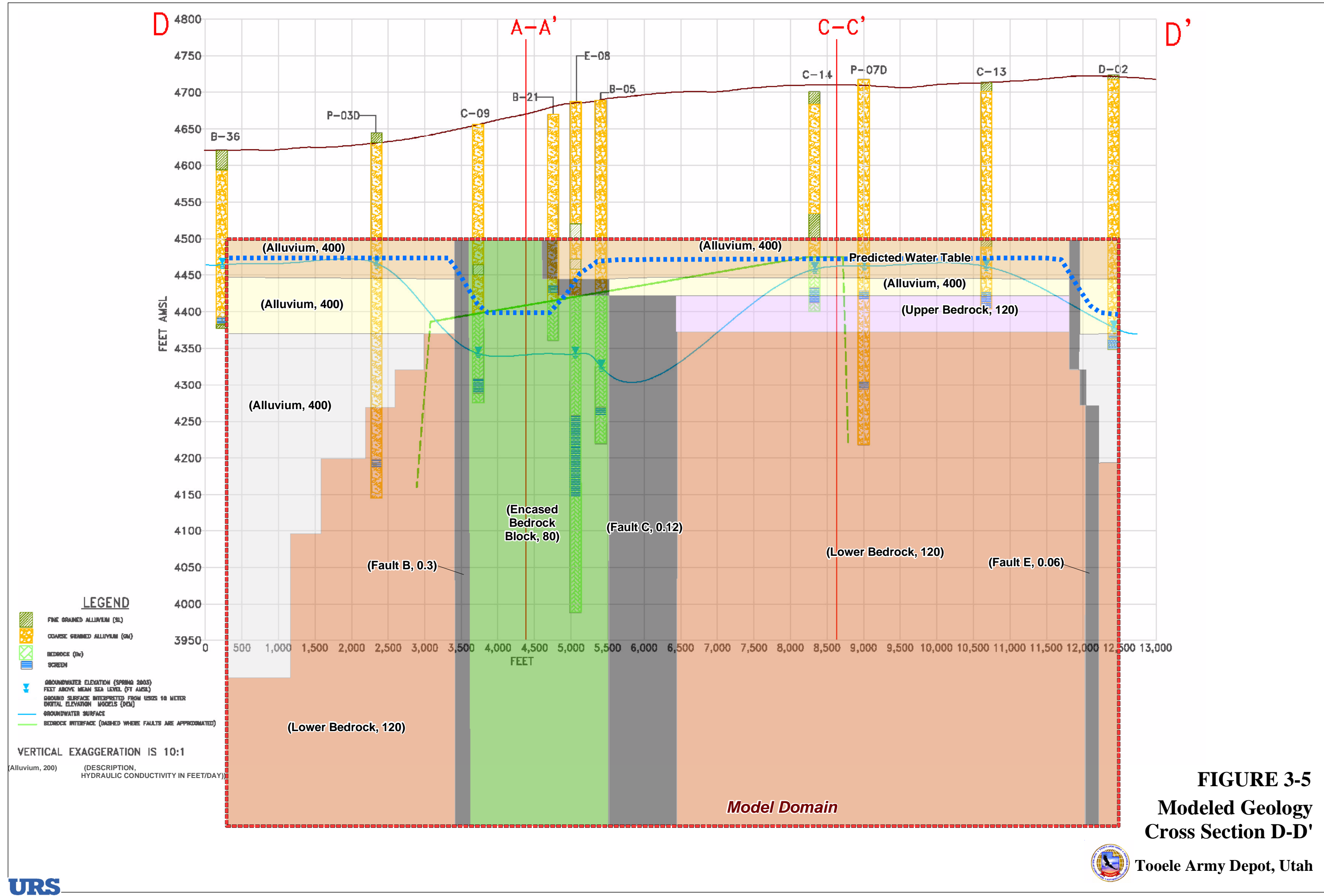


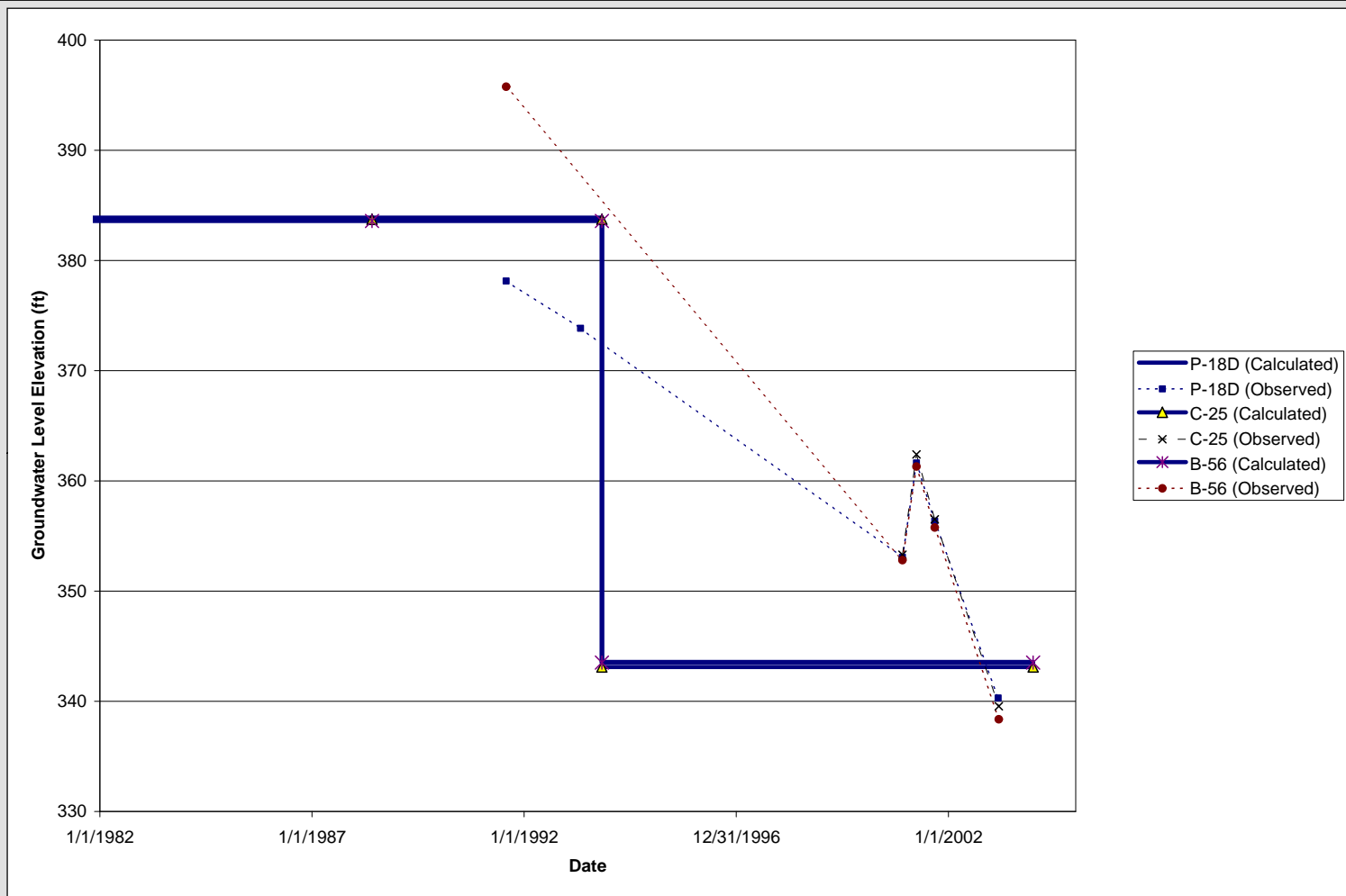


**FIGURE 3-4**  
**Modeled Geology**  
**Cross Section C-C'**



Tooele Army Depot, Utah

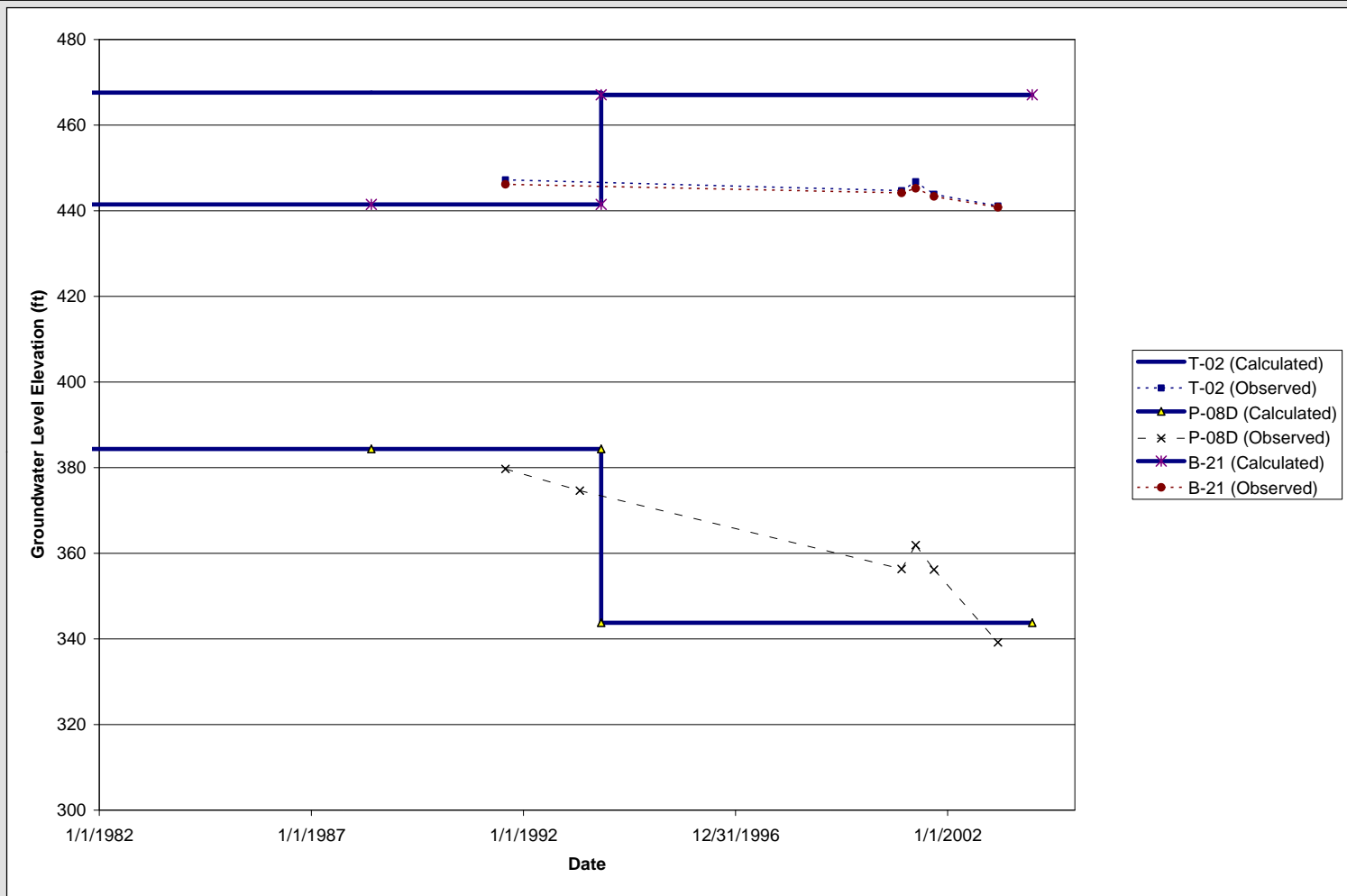




**FIGURE 3-6**  
**Head Versus Time in Bedrock Block**  
**at Monitoring Wells Very Near E-05**



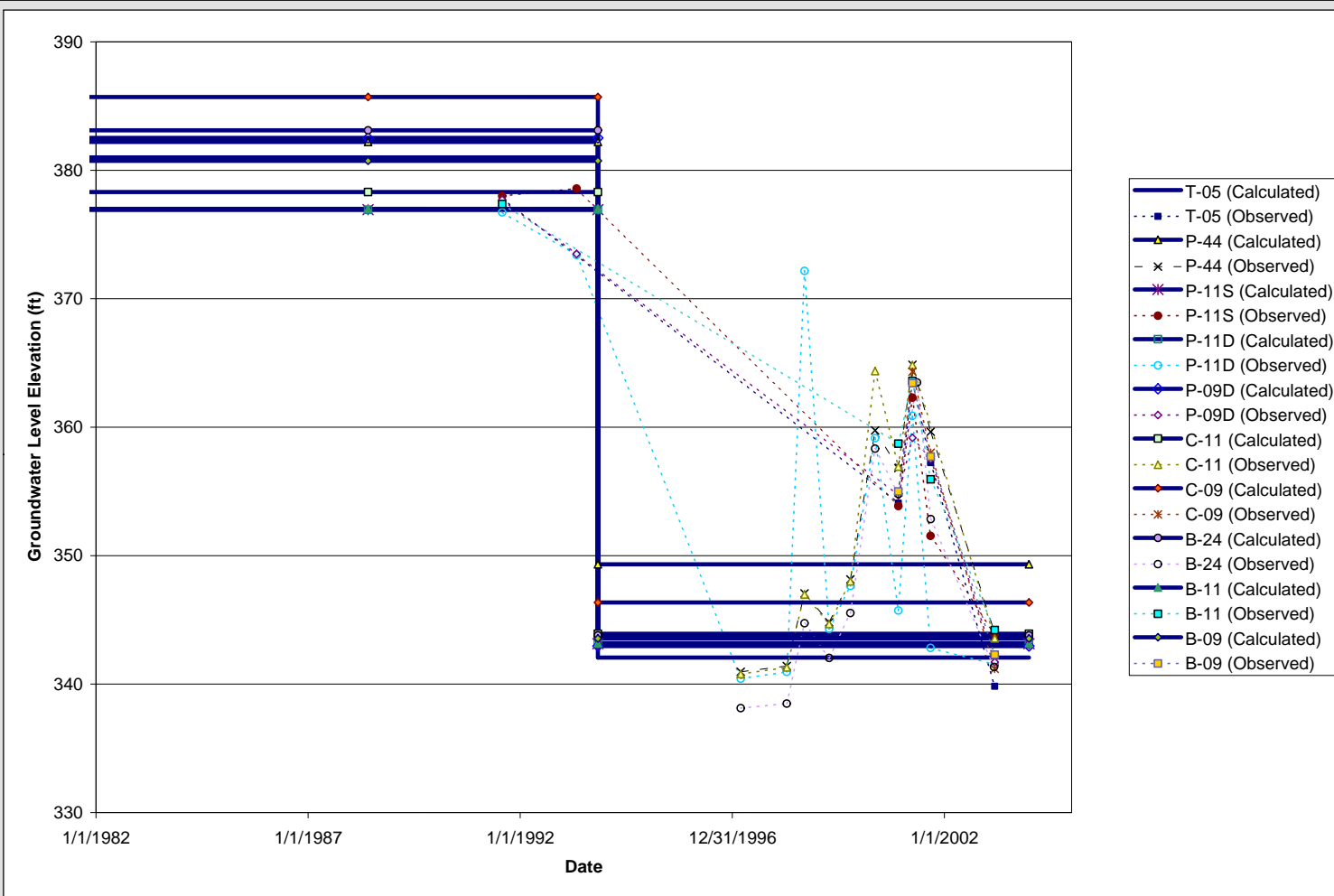
Tooele Army Depot, Utah



**FIGURE 3-7**  
**Head Versus Time in Bedrock Block**  
**at Monitoring Wells Very Near E-05 and E-08**



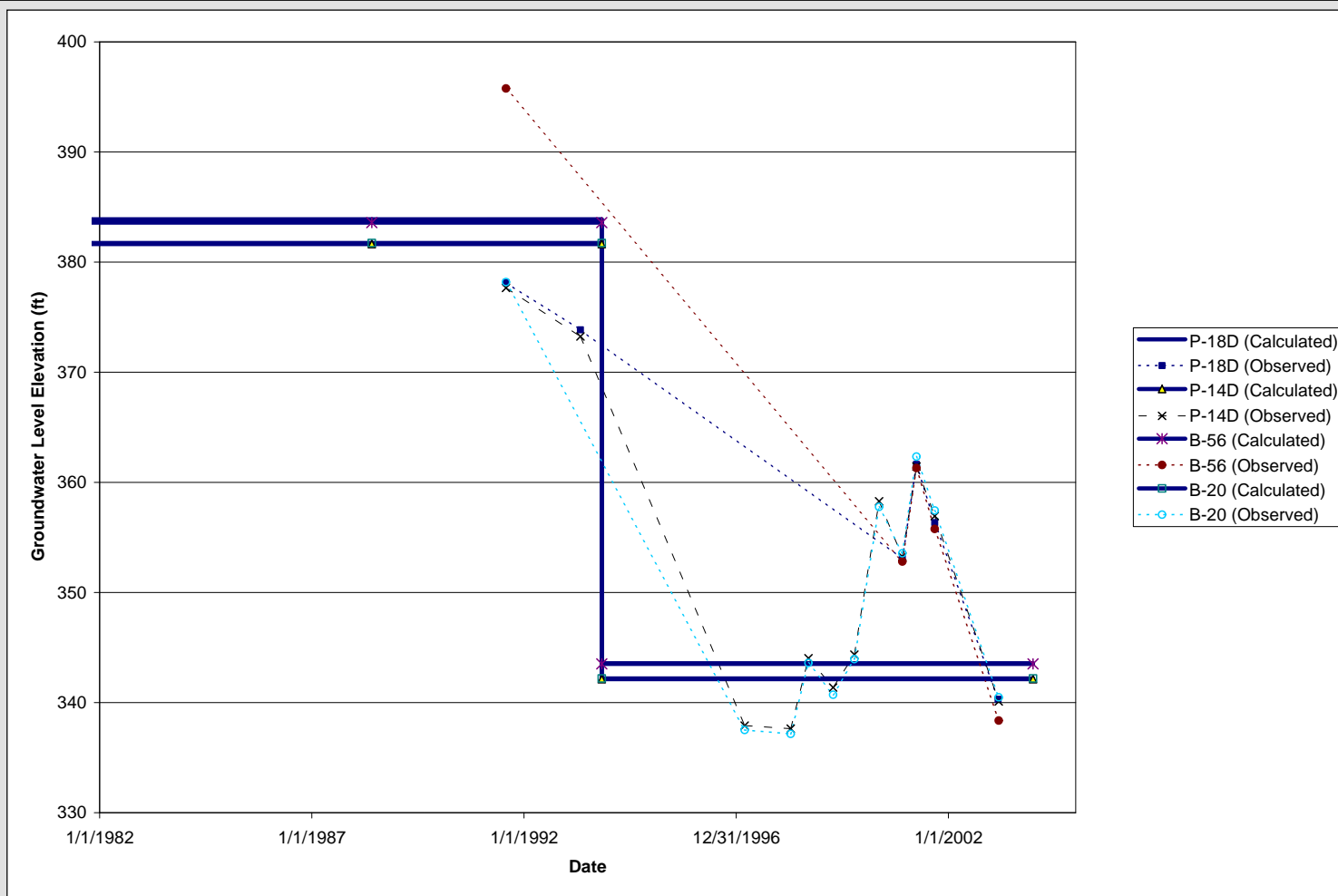
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**FIGURE 3-8**  
**Head Versus Time in Bedrock Block at**  
**Monitoring Wells Far from E-05, E-08, E-09, E-10, and E-04**



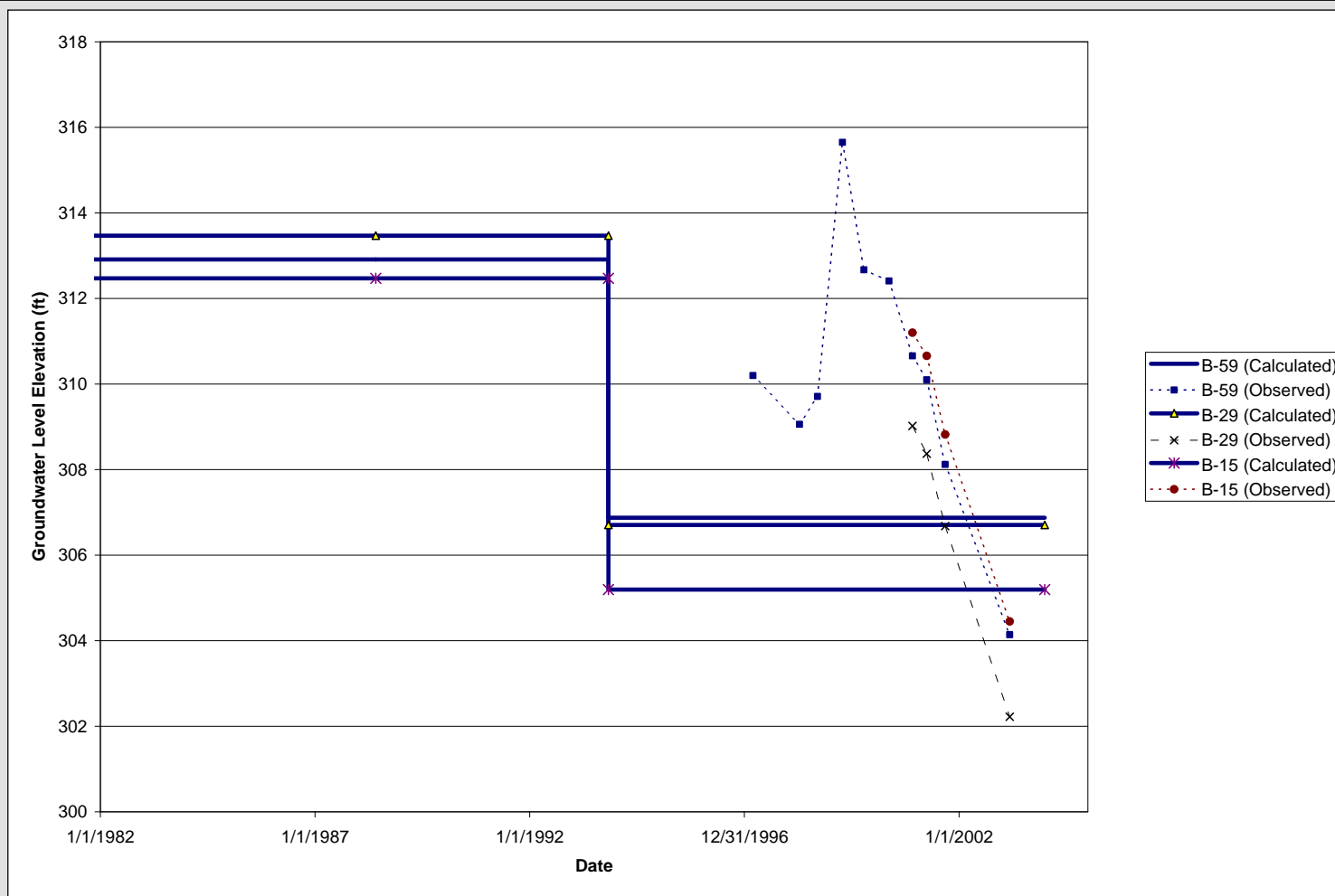
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**FIGURE 3-9**  
**Head Versus Time Well Pairs in Bedrock Block**



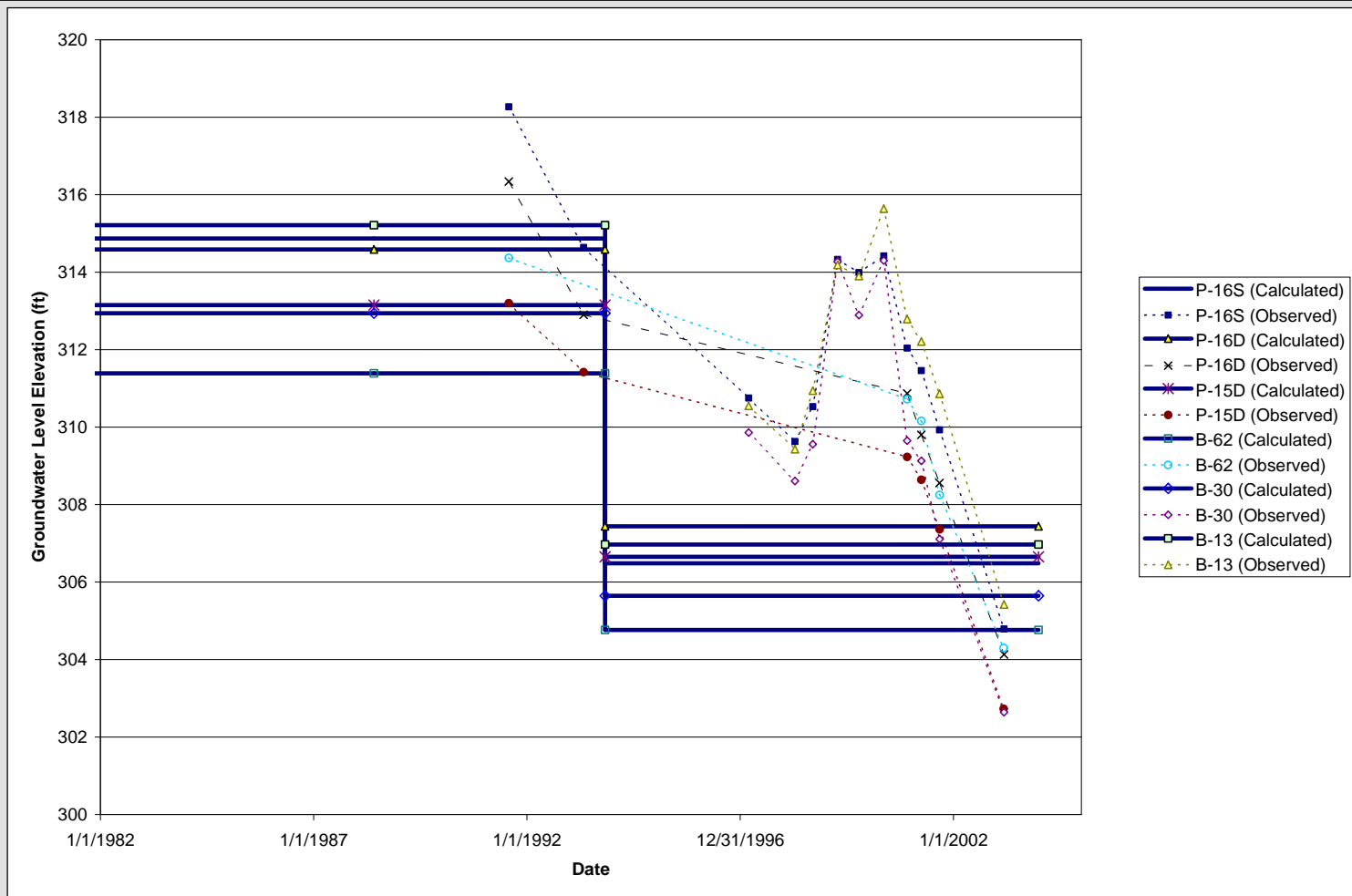
Tooele Army Depot, Utah



**FIGURE 3-10**  
**Head Versus Time North of Bedrock**  
**Block at Monitoring Wells Near E-02**



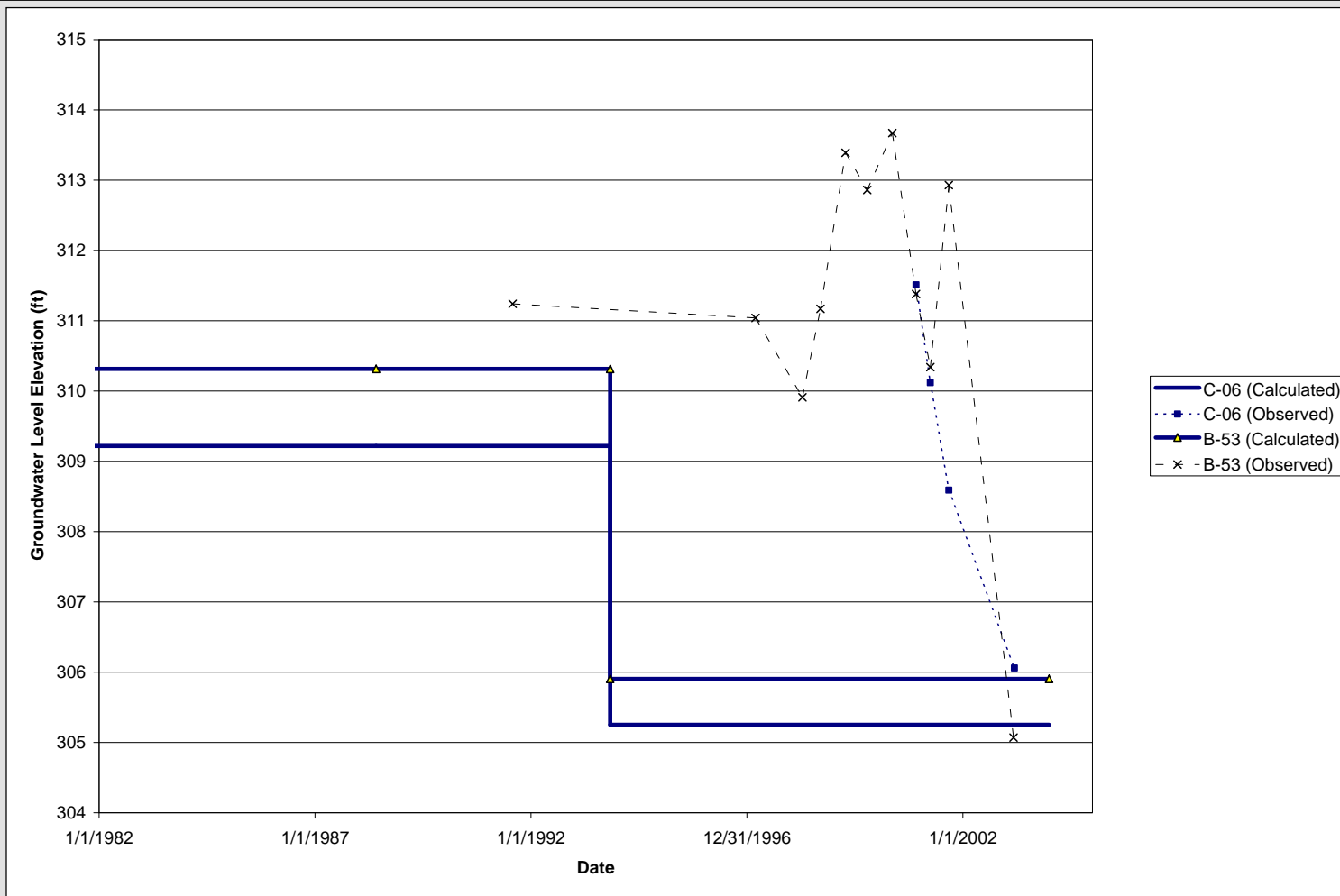
Tooele Army Depot, Utah



**FIGURE 3-11**  
**Head Versus Time North of Bedrock Block**  
**at Monitoring Wells Far from E-02, E-13, and E-14**



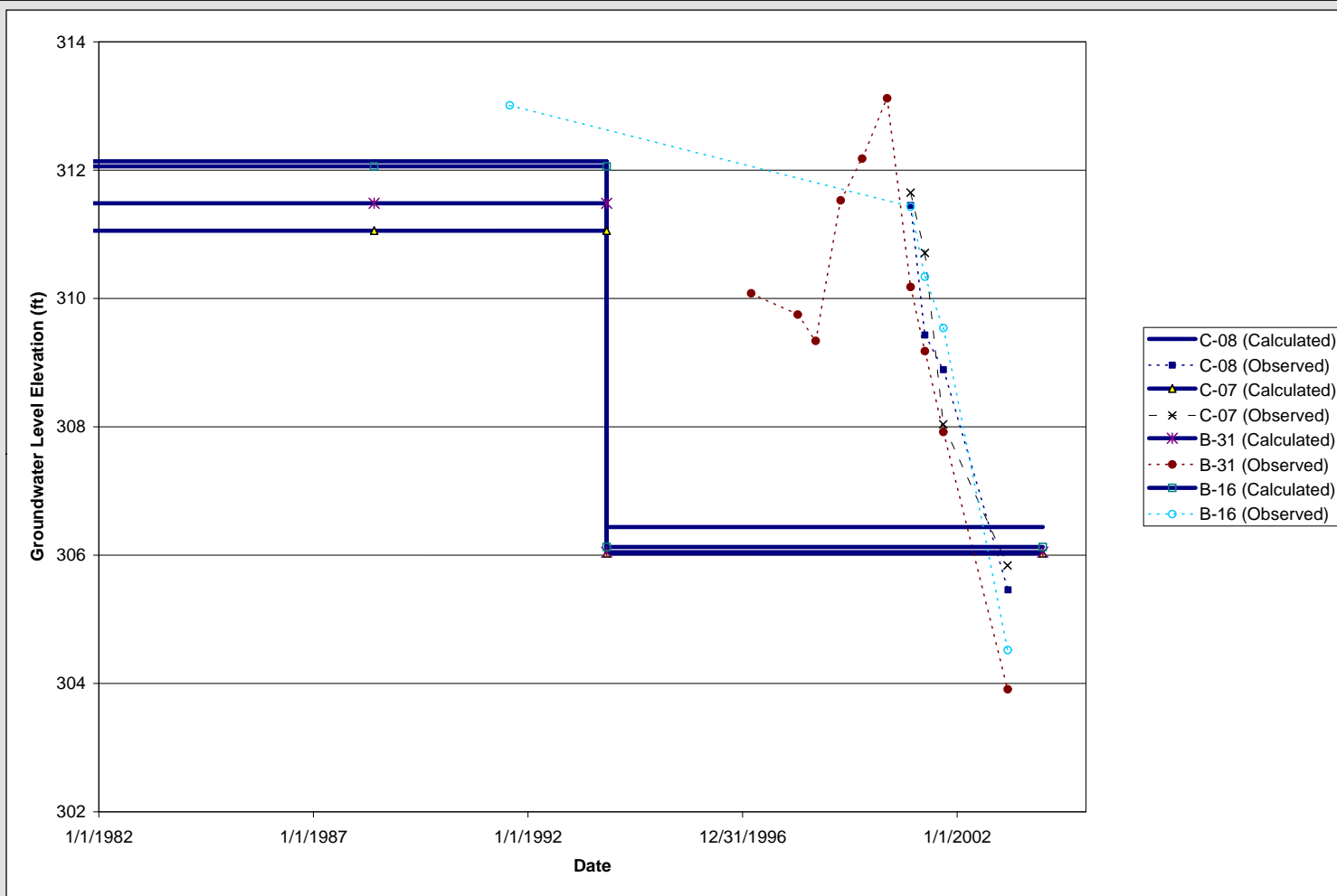
Tooele Army Depot, Utah



**FIGURE 3-12**  
**Head Versus Time North of Bedrock Block**  
**at Monitoring Wells Near I-02 and I-03**



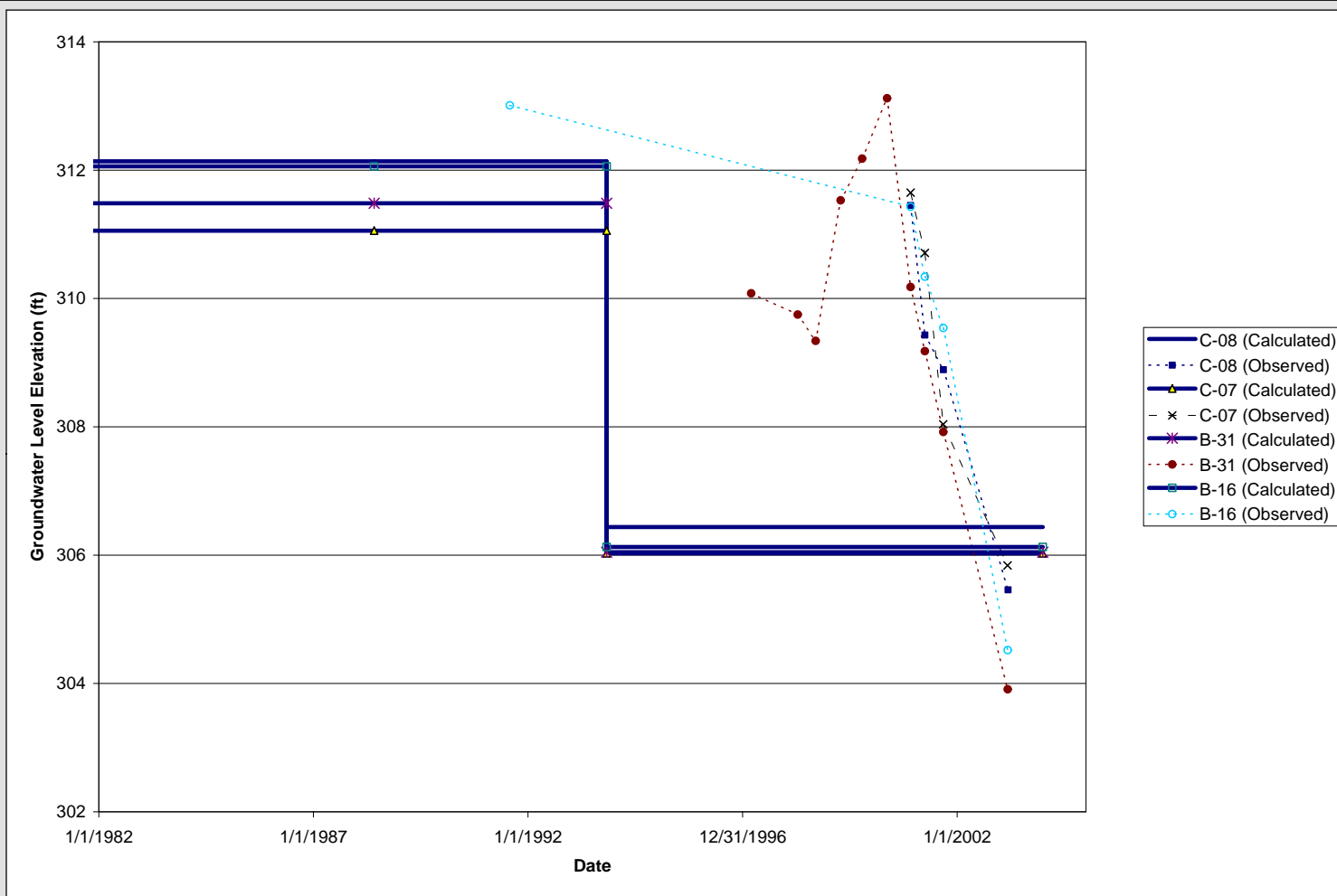
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**FIGURE 3-13**  
**Head Versus Time North of Bedrock Block**  
**at Monitoring Wells Far from I-01 and I-02**



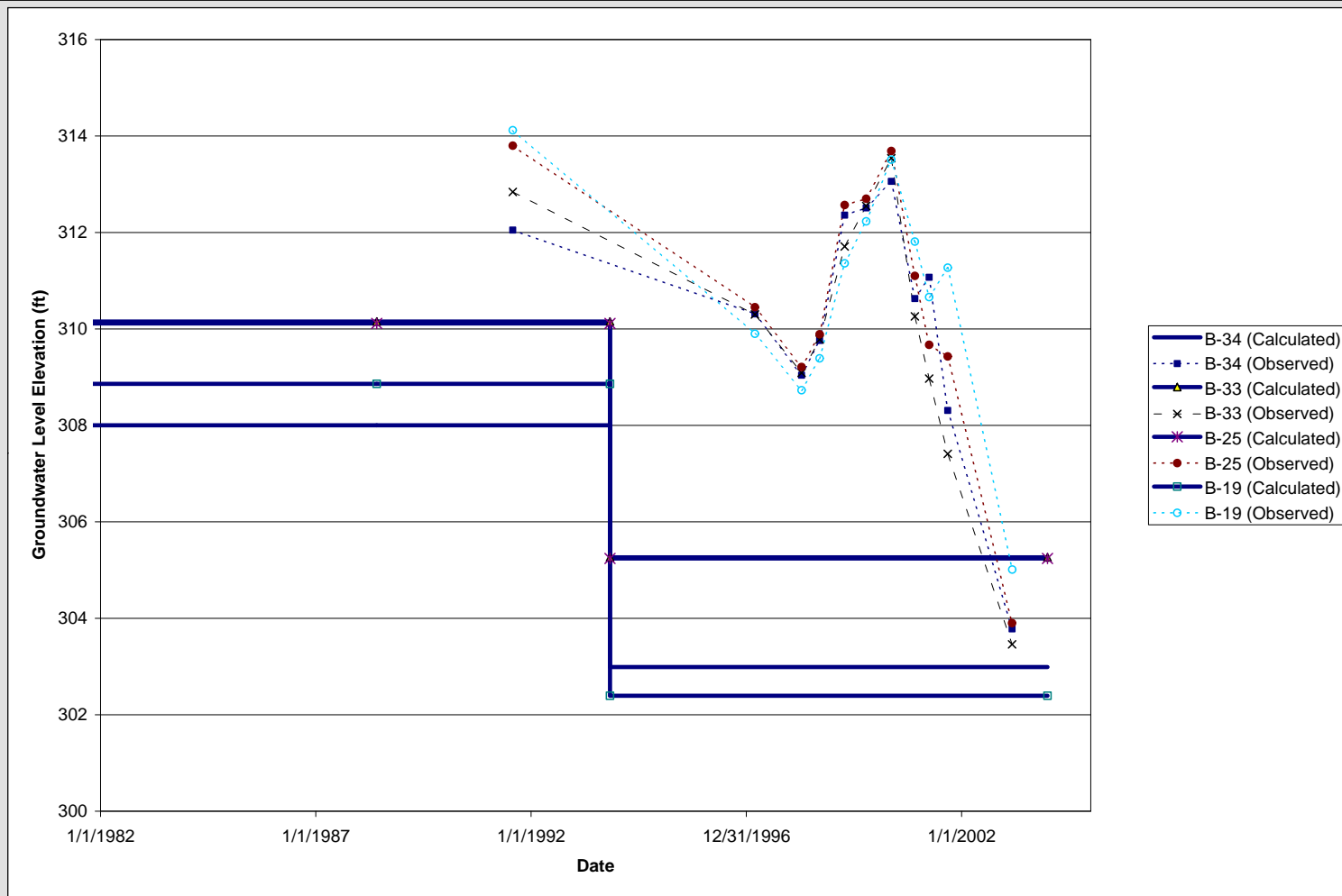
Tooele Army Depot, Utah



**FIGURE 3-13**  
**Head Versus Time North of Bedrock Block**  
**at Monitoring Wells Far from I-01 and I-02**



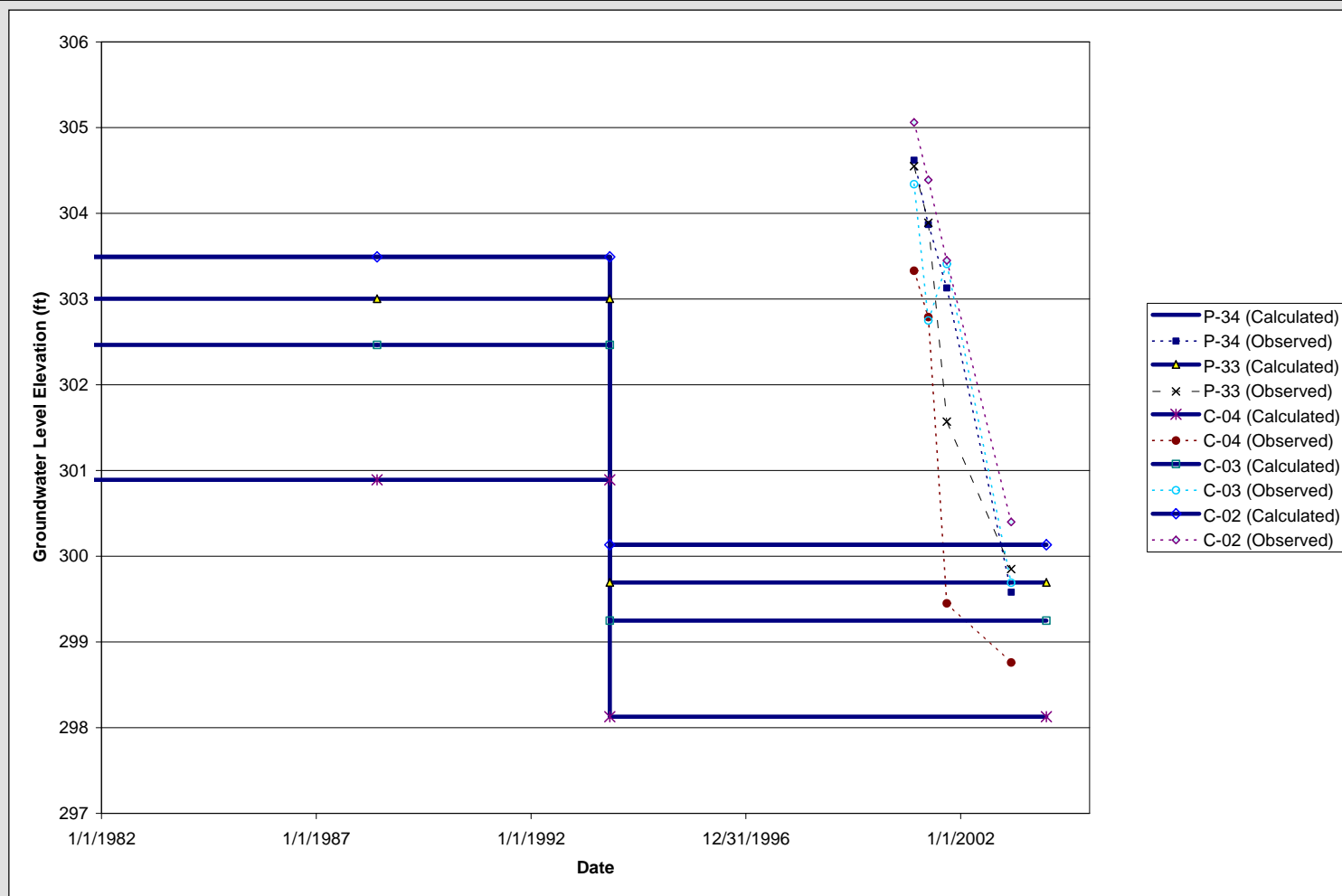
Tooele Army Depot, Utah



**FIGURE 3-14**  
**Head Versus Time North of Bedrock Block**  
**at Monitoring Wells Near E-11**



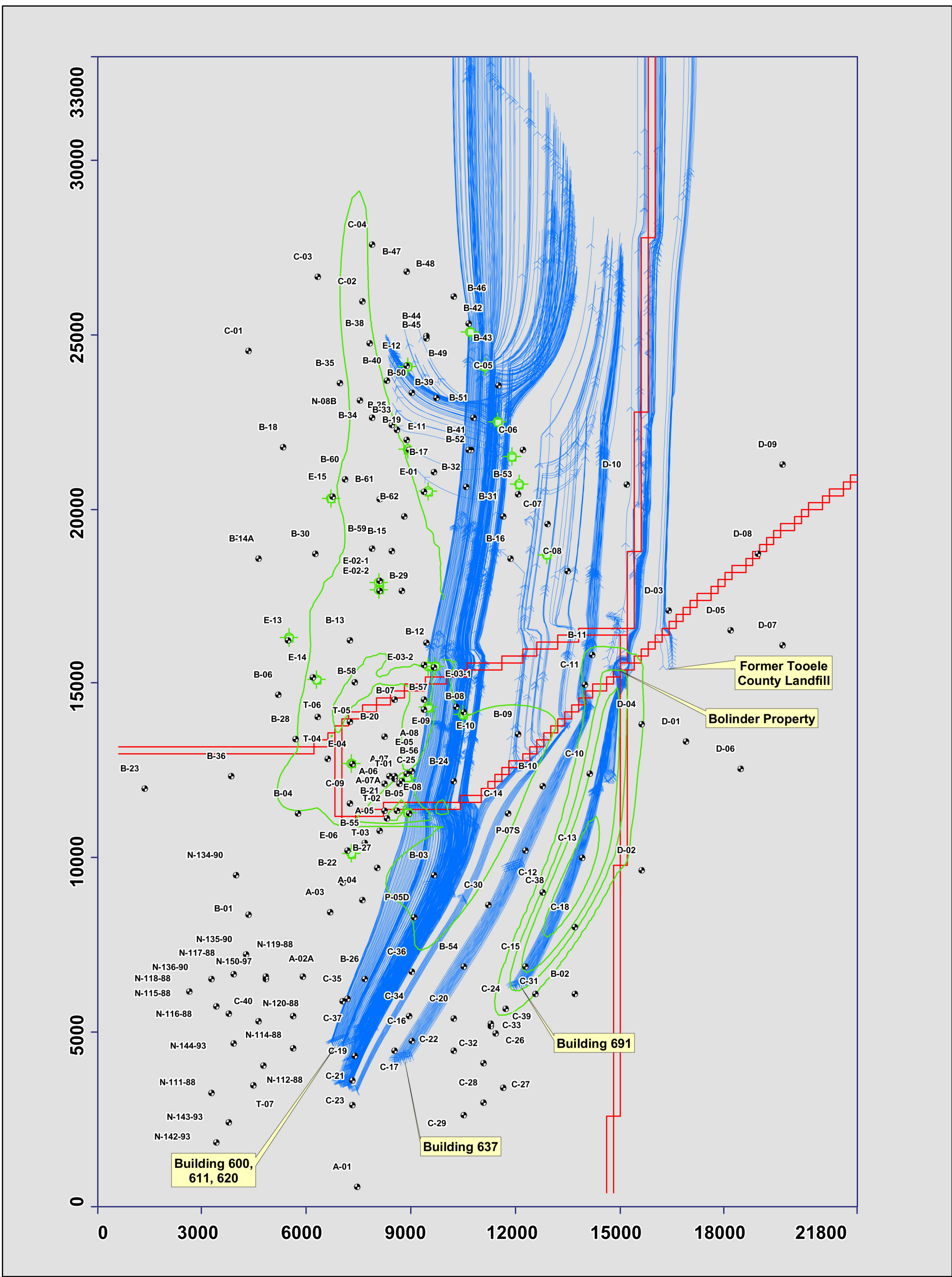
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**FIGURE 3-15**  
**Head Versus Time North of Bedrock Block**  
**at North Edge of Main Plume**



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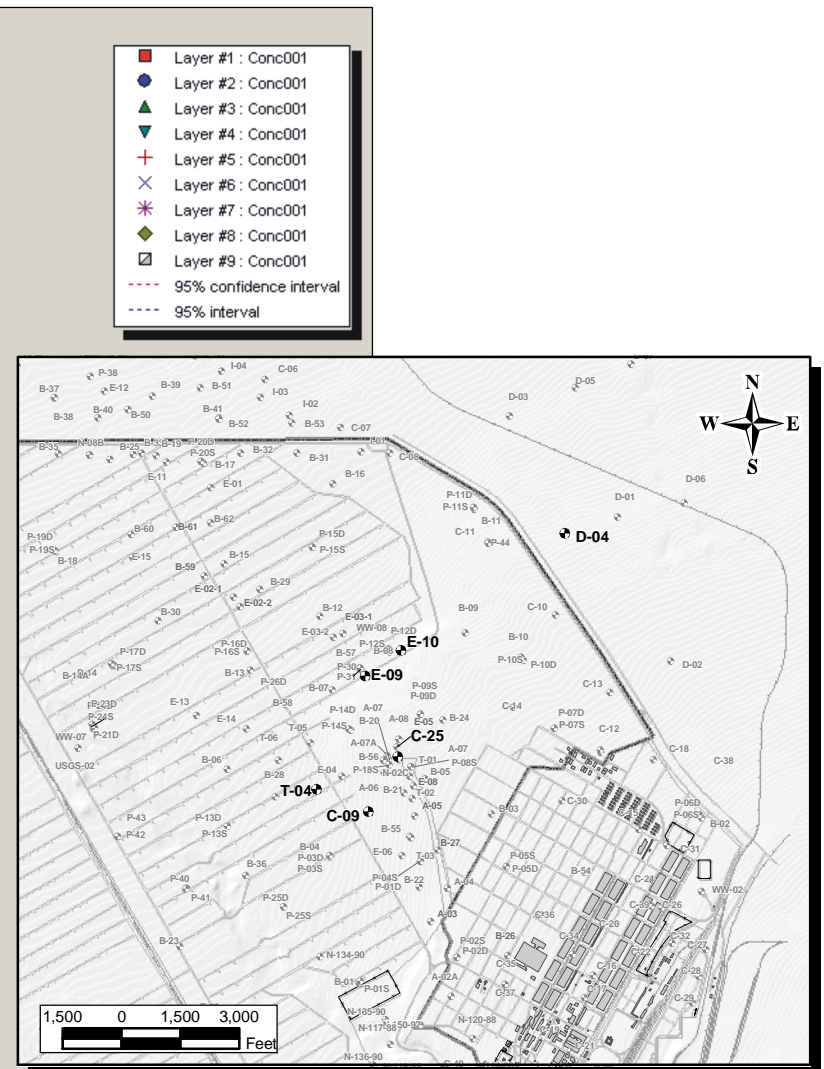


**FIGURE 3-16**  
**Particle Tracking from Alternate**  
**Source Locations**



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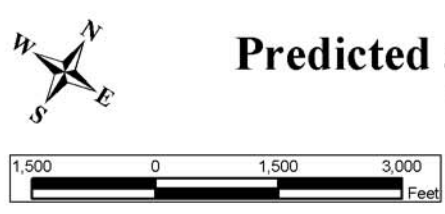
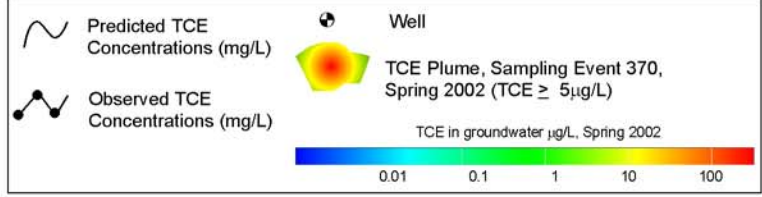
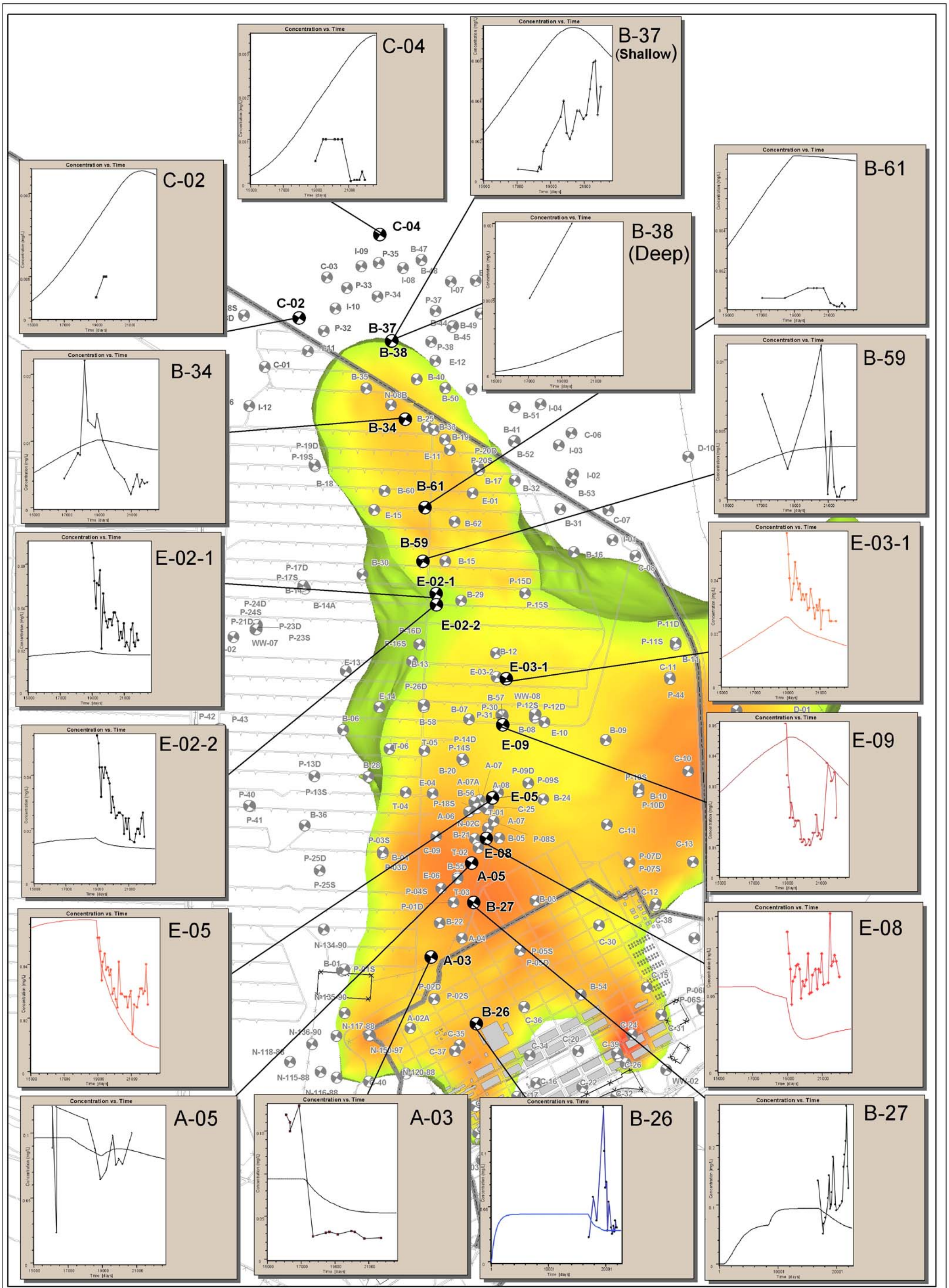




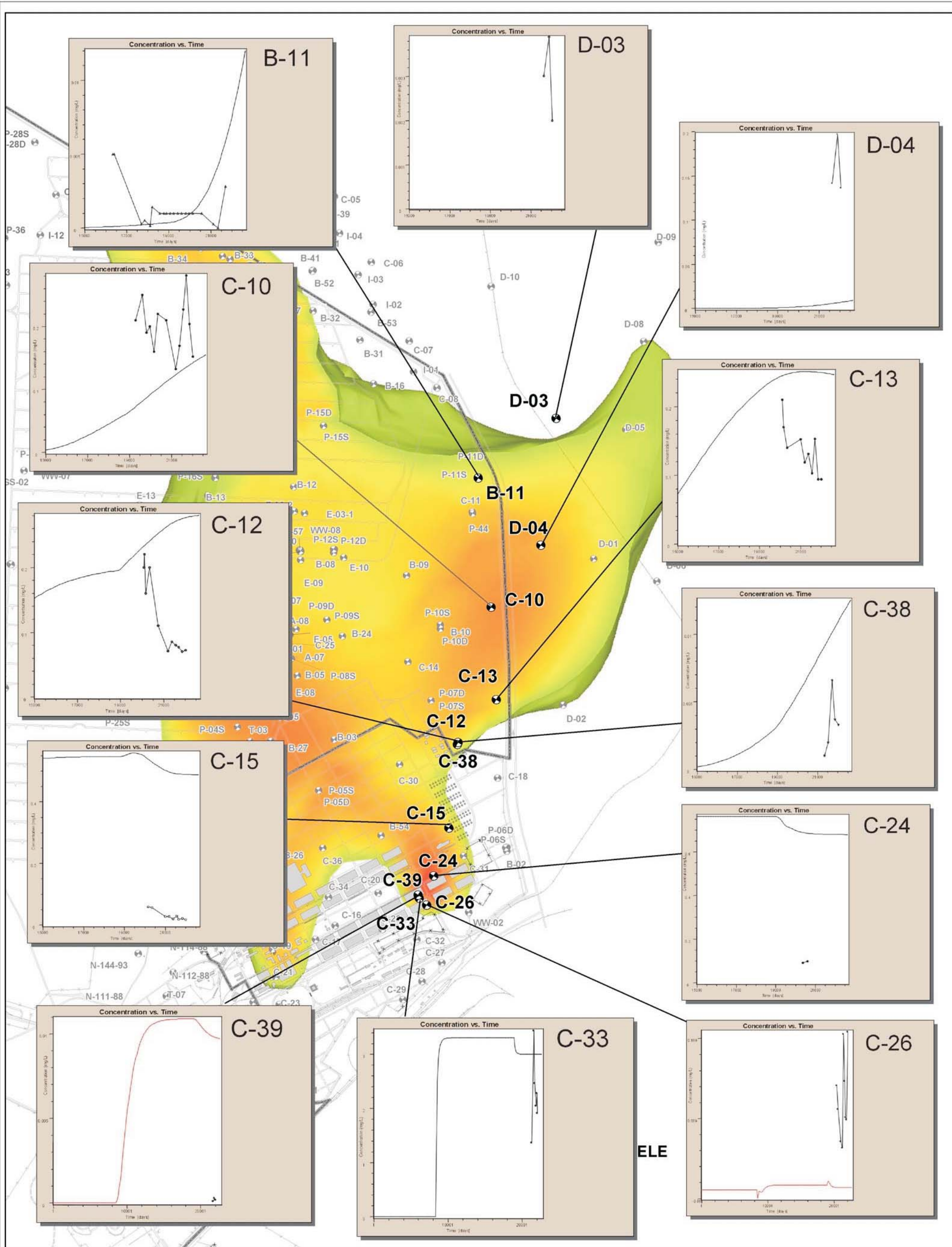
Standard Error of the Estimate : 0.002 (mg/L)  
Root Mean Squared : 0.018 (mg/L)  
Normalized RMS : 11.678 ( % )  
Correlation Coefficient : 0.776

## Tooele Army Depot, Utah





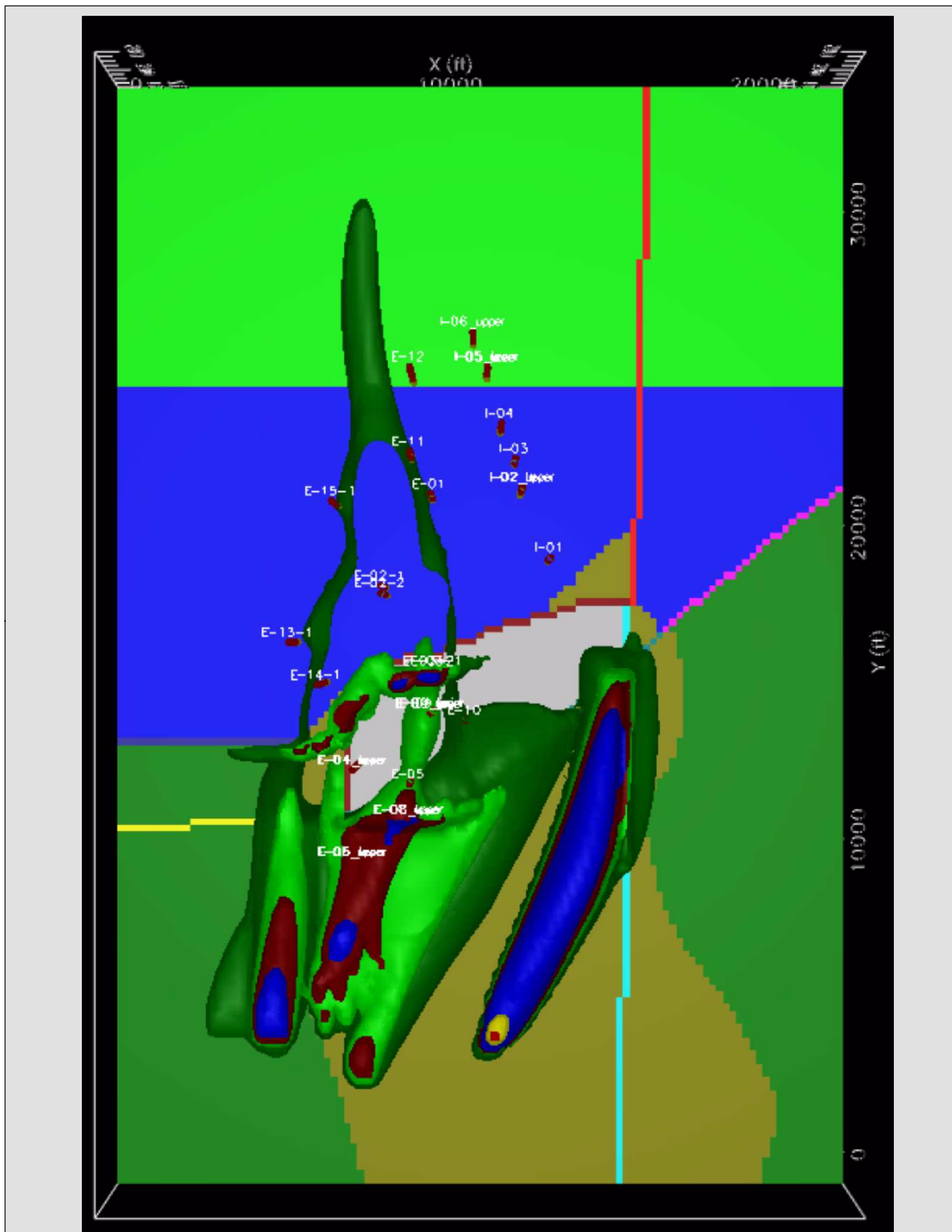
**FIGURE 3-19**  
**Predicted and Observed TCE Concentration**  
**Time Histories In the Main Plume**



**FIGURE 3-20**  
**Predicted and Observed TCE Concentration**  
**Time Histories In the Northeast Boundary**

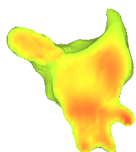
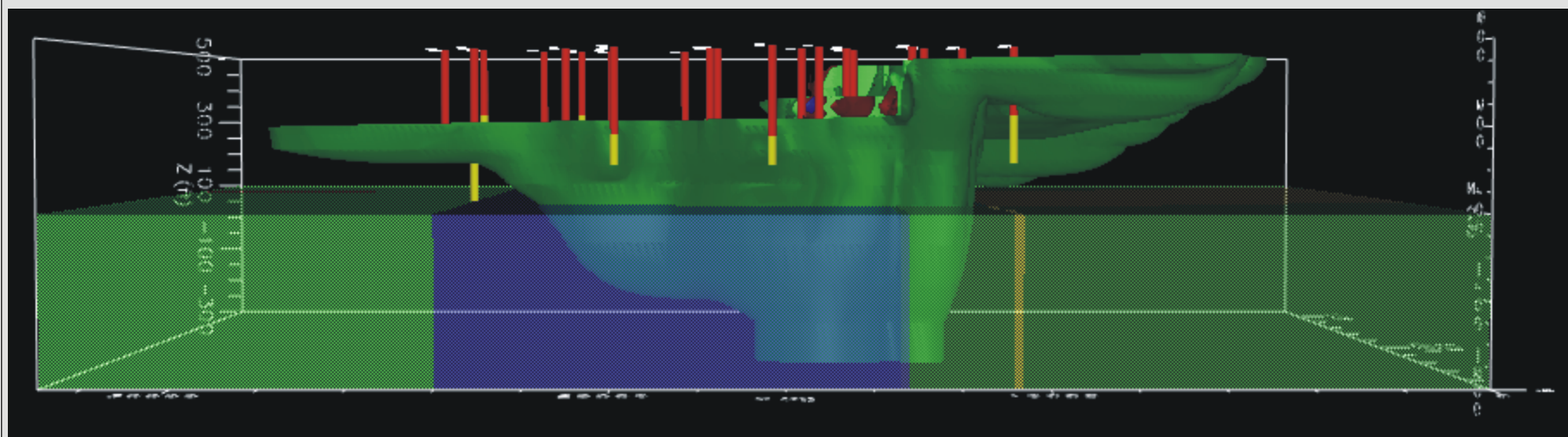


Tooele Army Depot, Utah



**FIGURE 3-21**  
**Three-Dimensional Predicted TCE Plume:**  
**Plan View**

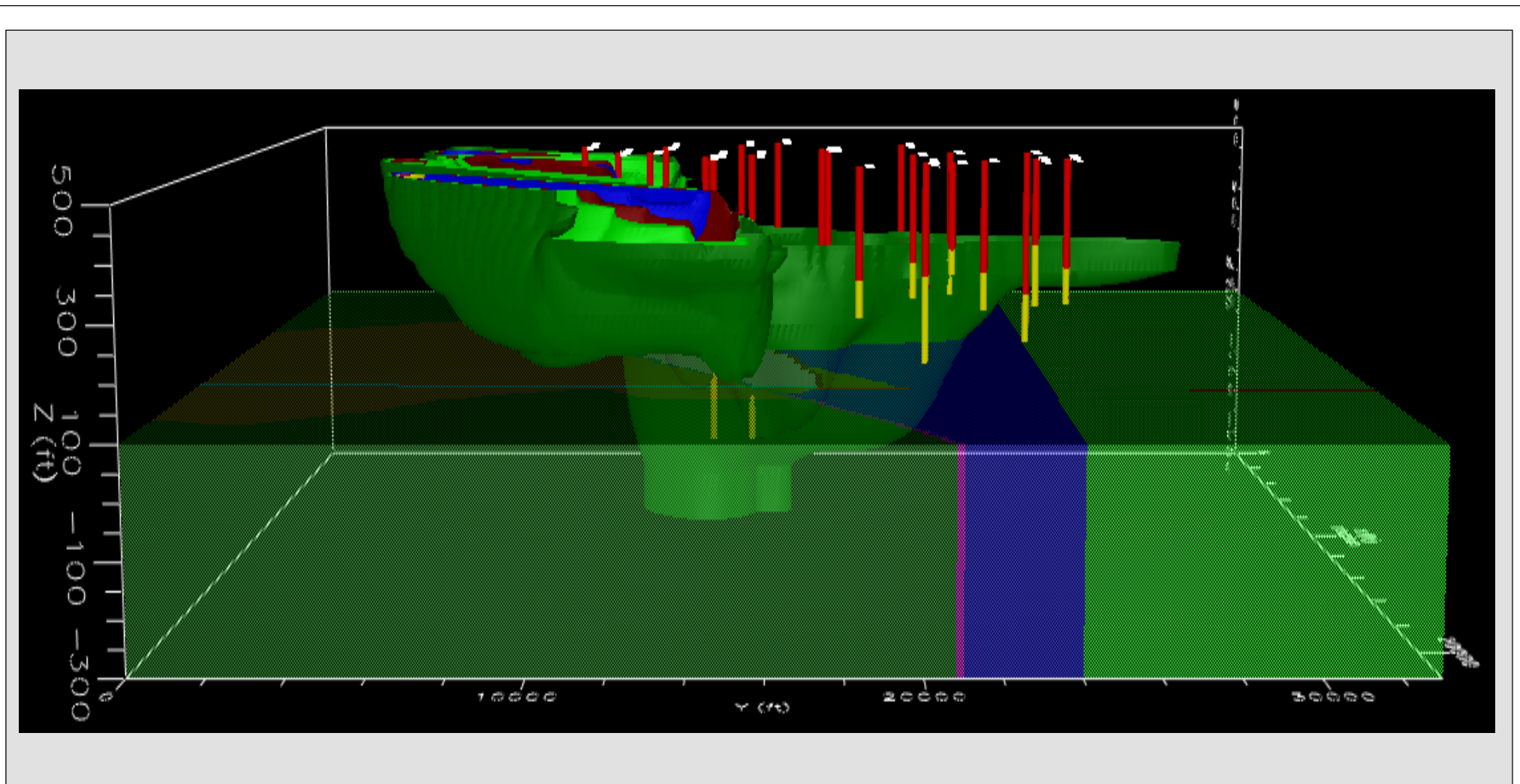




**FIGURE 3-22**  
**Three Dimensional Predicted TCE Plume:**  
**View from the Southwest**



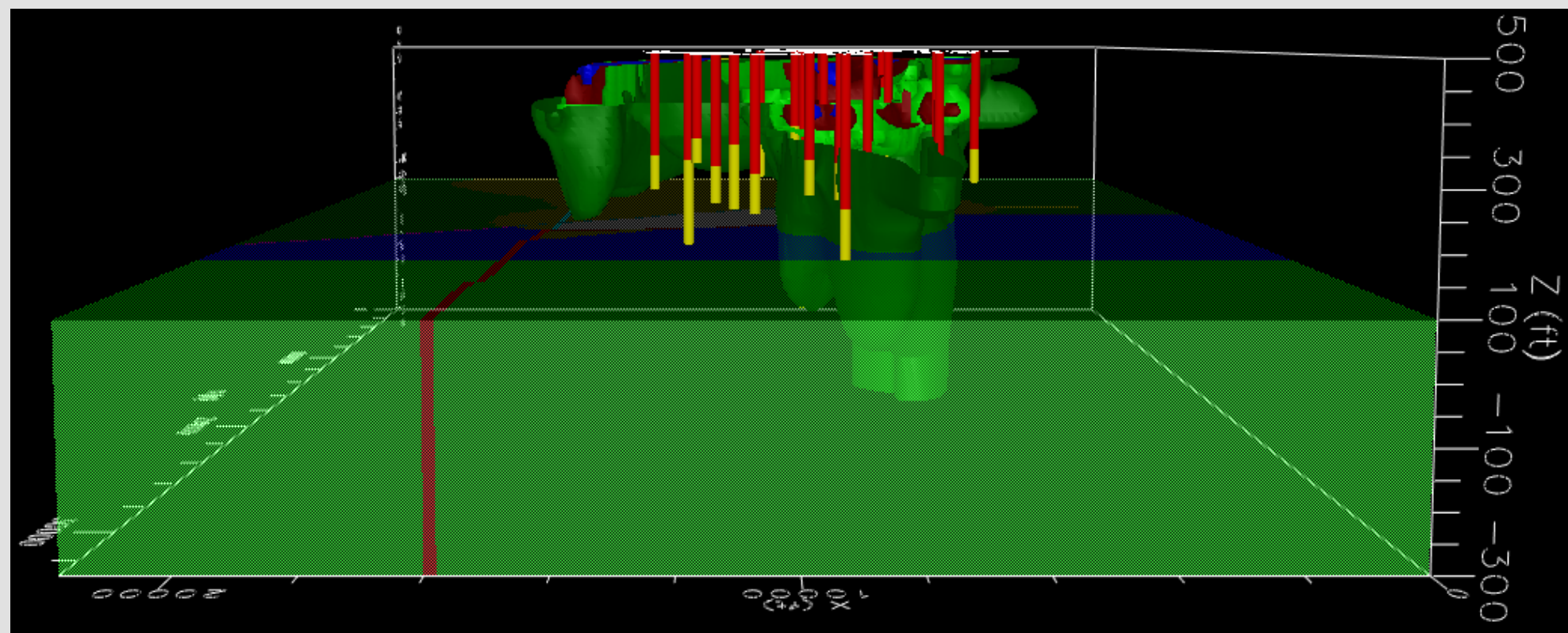
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**FIGURE 3-23**  
**Three Dimensional Predicted TCE Plume:**  
**View from the Northeast**



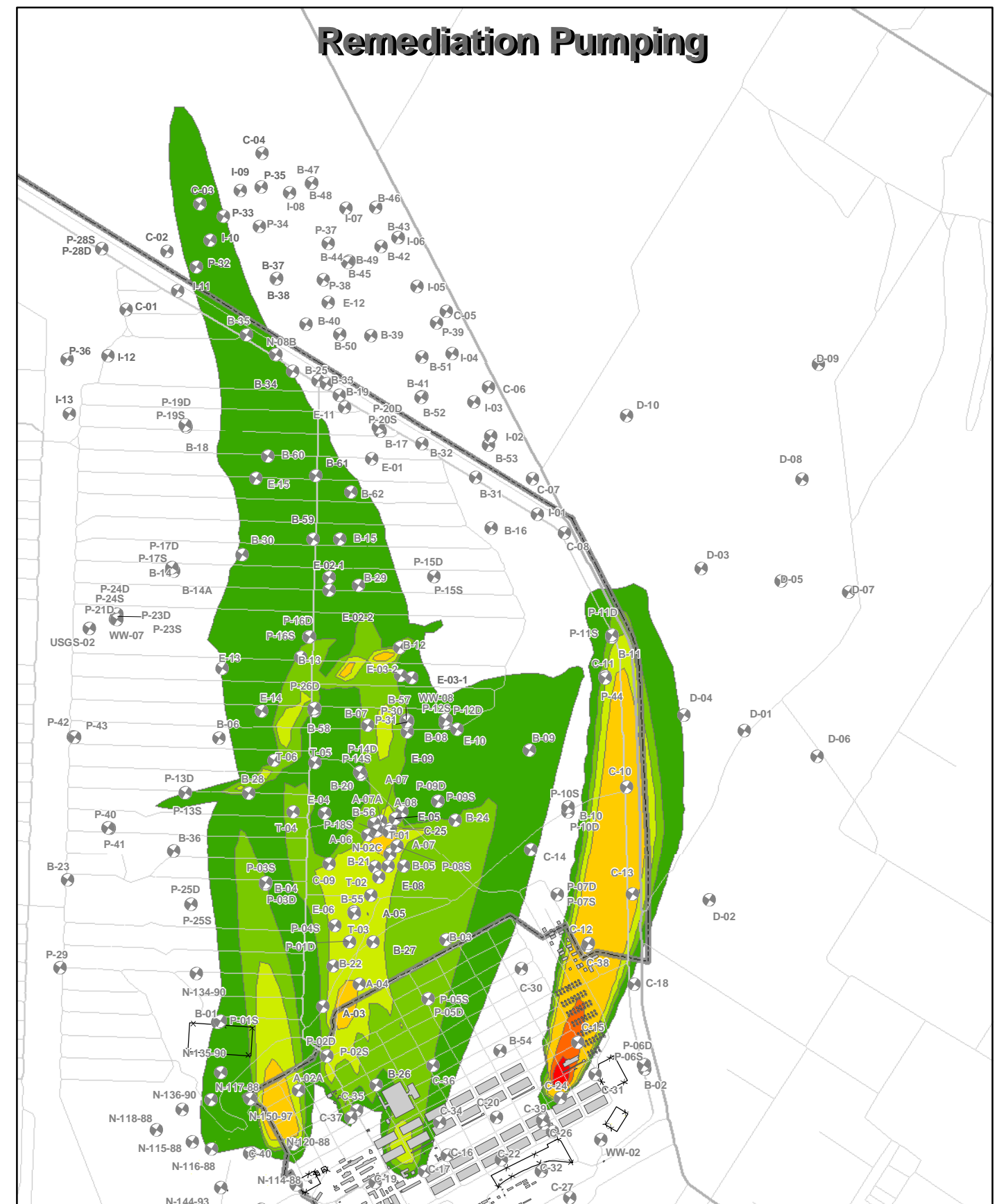
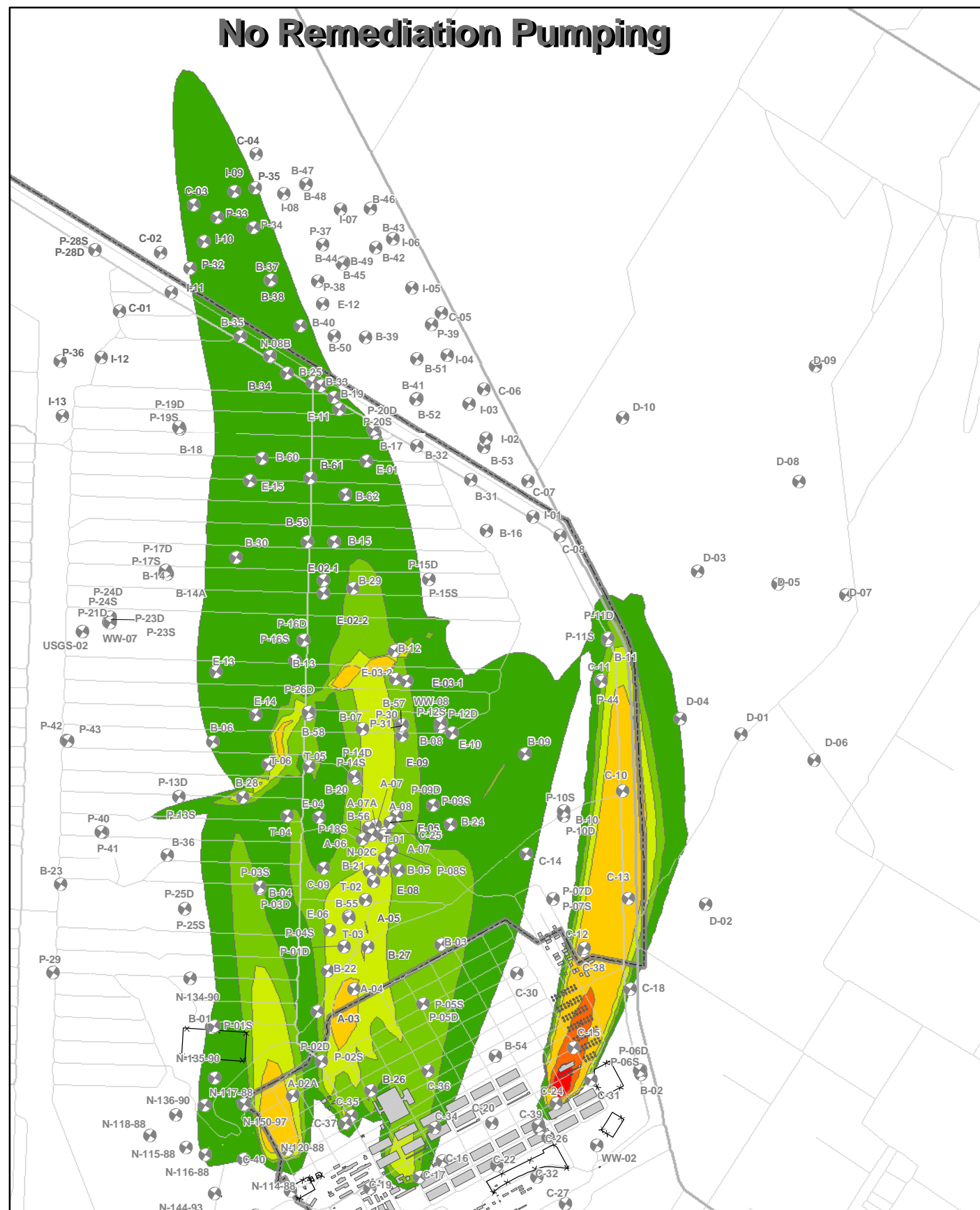
Tooele Army Depot, Utah



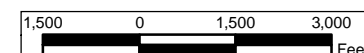
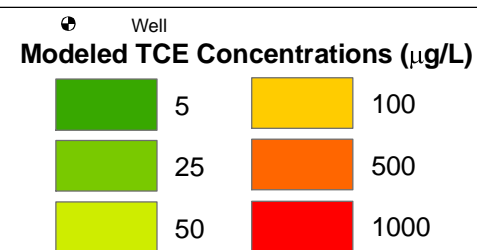
**FIGURE 3-24**  
**Three Dimensional Predicted TCE Plume:**  
**View from the Northwest**



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Updated: 12/17/03



**FIGURE 4-1**  
**Predicted Current Plume With and**  
**Without Operation of Remedial System**



Tooele Army Depot, Utah

## APPENDIX A: DETAILED MODEL REVIEW REPORT

### MODEL REVIEW: 1. THE REPORT

Q.	QUESTION	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0 or 5)	COMMENT
1.1	Is a report provided?	Not Applicable	No			<b>Yes</b>	5	5	-
1.2	Are relevant prior or companion reports provided or accessible?	Not Applicable	No	<b>Some</b>	Yes		1	5	Some provided or accessible, others not
1.3	3 Is it clear which person(s) did the modeling?	Not Applicable	No		<b>Yes</b>		3	3	-
1.4	Is the report well structured?	Not Applicable		Deficient	Adequate	<b>Exemplary</b>	5	5	-
1.5	Is the report presentation of acceptable quality?	Not Applicable		Deficient	Adequate	<b>Exemplary</b>	5	5	-
1.6	Is there a clear statement of project objectives?	Not Applicable	Missing	Deficient	Adequate	<b>Exemplary</b>	3	5	Decision making tool for various design scenarios
1.7	Is the fidelity level of the model clear or acknowledged	Not Applicable	Missing	No	Maybe	<b>Yes</b>	5	5	In general and in various places
1.8	Are model parameter distributions disclosed?	Not Applicable	Missing	Deficient	Adequate	<b>Exemplary</b>	5	5	Yes (some figure labeling missing)
1.9	Are model parameter statistics reported (median, range, standard deviation)?	Not Applicable	Missing	Deficient	<b>Adequate</b>	Exemplary	3	5	Yes – flow No - transport
1.10	Is it clear how stress datasets have been compiled?	Not Applicable	Missing	Deficient	Adequate	<b>Exemplary</b>	5	5	Detailed in appendices B and C
1.11	Would it be possible to re-create the structure of the model from what is reported?	Not Applicable	Missing	No	Maybe	<b>Yes</b>	5	5	Yes. Also model files were provided.
1.12	Is a water or mass balance reported?	Not Applicable	Missing	Deficient	<b>Adequate</b>	Exemplary	3	5	Yes – flow Transport mass balance info split between text and figures.

Q.	QUESTION	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0 or 5)	COMMENT
1.13	Are recommendations reasonable and supported by evidence?	Not Applicable	Missing	Deficient	Adequate	Exemplary	4	5	Effect of mismatch between predicted and observed TCE levels in NEB plume on short-term remedial actions not addressed
1.14	Has the modeling study satisfied project objectives?	Not Applicable	Missing	Deficient	Adequate	Exemplary	4	5	
1.15	Are the model results of any practical use?	Not Applicable		No	Maybe	Yes	4	5	Yes but a more detailed uncertainty analysis would allow cost versus benefit of additional data gathering to be quantified
1.16	Has the modeling study been cost- effective?	Not Applicable		No	Maybe	Yes	0	0	Cannot evaluate
1	<b>TOTAL SCORE</b>						<b>60</b>	<b>73</b>	

## MODEL REVIEW: 2. DATA ANALYSIS

Q.	QUESTION	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0 or 5)	COMMENT
2.1	Have prior investigations been examined and acknowledged?		Missing	Deficient	Adequate	<b>Exemplary</b>	5	5	Detailed in Section 2.6 and Appendix A
2.2	Is current knowledge sufficient for a mathematical model?			No	Maybe	<b>Yes</b>	5	5	Additional source and fault characterization would reduce uncertainties
2.3	Is there a cost- effective alternative to modeling which would satisfy the project objectives?			Yes	Maybe	<b>No</b>	5	5	Leaching tests and unsaturated zone modeling might better define future sources for the predictive runs
2.4	Has a literature review been completed?	Not Applicable	Missing	Deficient	Adequate	<b>Exemplary</b>	5	-	Exhaustive reference list
2.5	Has hydrogeology data been collected and analyzed?		Missing	Deficient	Adequate	<b>Exemplary</b>	5	5	Yes – in Sections 2 and 3, with details provided in referenced reports
2.6	Has rainfall data been collected and analyzed?	<b>Not Applicable</b>	Missing	Deficient	Adequate	Exemplary	0	0	Recharge is only 1% of total inflow, therefore model insensitive to recharge rates.
2.7	Has streamflow data been collected and analyzed?	<b>Not Applicable</b>	Missing	Deficient	Adequate	Exemplary	0	0	No perennial streams in modeled area
2.8	Has groundwater usage data been collected and analyzed?	Not Applicable	Missing	Deficient	<b>Adequate</b>	Exemplary	3	5	Pumpage detailed in Appendix B, 111 gpm discharge at IWL (1965 - 1988) ignored for flow calculations, but treated as TCE source in transport calculations
2.9	Has evapotranspiration data been collected and analyzed?	<b>Not Applicable</b>	Missing	Deficient	Adequate	Exemplary	0	0	Little vegetation in modeled area
2.10	Has irrigation data been collected and analyzed?	<b>Not Applicable</b>	Missing	Deficient	Adequate	Exemplary	0	0	No irrigation in modeled area
2.11	Has flood event data been collected and analyzed?	<b>Not Applicable</b>	Missing	Deficient	Adequate	Exemplary	0	0	-

Q.	QUESTION	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0 or 5)	COMMENT
2.12	Has drainage data been collected and analyzed	Not Applicable	Missing	Deficient	Adequate	Exemplary	3	5	Ditches, sumps, leaky lines, and stormwater impoundment probably resulted in minor contribution of flow. These sources were accounted for in the transport model.
2.13	Has other data been collected and analyzed	Not Applicable	Missing	Deficient	Adequate	Exemplary	5	5	Water levels versus faults and aquifer pumping test results, flow balances in other USGS studies, vertical hydraulic gradients, thermal gradients, and TDS variation. Details provided in referenced reports.
2.14	Have the above stress datasets been analyzed for their groundwater response	Not Applicable	Missing	Deficient	Adequate	Exemplary	0	0	Data unavailable
2.15	Is any relevant dataset ignored		Yes	Maybe		No	5	5	Re-interpretation of bedrock surface in URS (2003) may need to be incorporated into model structure
2.16	Are residual mass (cumulative deviation) plots prepared for rainfall / streamflow	Not Applicable	Missing	Deficient	Adequate	Exemplary	0	0	-
2.17	Is groundwater hydrographic data available	Not Applicable		No	Maybe	Yes	5	5	Since approximately 1989
2.18	Are representative hydrographs selected logically	Not Applicable	Missing	Deficient	Adequate	Exemplary	2	5	Hydrographs showing variations not presented
2.19	Are field hydrographs compared and analyzed	Not Applicable	Missing	Deficient	Adequate	Exemplary	0	0	Steady state analysis
2.20	Is water table / piezometric surface data available			No	Maybe	Yes	5	5	Piezometric maps for 1968, 2001 available in referenced reports

Q.	QUESTION	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0 or 5)	COMMENT
2.21	Are representative contour maps selected logically	Not Applicable	Missing	Deficient	<b>Adequate</b>	Exemplary	3	5	Not presented in this report; presented in referenced reports
2.22	Is interpolation reliability clear to reader (posting of sample points, algorithm)?	Not Applicable	Missing	Deficient	<b>Adequate</b>	Exemplary	3	5	No interpolated head field data presented in this report. TCE data (Figure 4) interpolation logic not explained.
2.23	Are data units consistent			No	Maybe	<b>Yes</b>	5	5	-
2.24	Have standard geometrical datums been used			No	Maybe	<b>Yes</b>	5	5	NAD83 horizontal datum, NGVD vertical datum
2.25	If groundwater flow is likely to be affected by density; allowance been made for the effect in any way	<b>Not Applicable</b>	Missing	Deficient	Adequate	Exemplary	0	0	Saltwater wedge ignored (outside area of plume) although upward gradients may be related to fresh groundwater flow relative to the saltwater wedge at depth and beneath the Great Salt Lake. TCE and TDS concentrations and temperature variations too low for density effects to be significant other than locally
<b>2</b>	<b>TOTAL SCORE</b>						<b>64</b>	<b>75</b>	

### MODEL REVIEW: 3. CONCEPTUALIZATION

Q.	QUESTION	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0 or 5)	COMMENT
3.1	Is the conceptual model consistent with prior knowledge?		Unknown	No	Maybe	Yes	5	5	Low conductivity faults/bedrock encasement postulated in model
3.2	Is the conceptual model consistent with project budget?	Not Applicable	Unknown	No	Maybe	Yes	0	0	Budget unknown
3.3	Is the conceptual model consistent with project objectives and the required model fidelity		Unknown	No	Maybe	Yes	4	5	Source assumptions for the Building 679 source may be exaggerated because the NEB plume concentrations are consistently over-predicted by the model
3.4	Is the conceptual model consistent with project deadline?	Not Applicable	Unknown	No	Maybe	Yes	0	0	Schedule unknown
3.5	Is there a clear description of the conceptual model?	Not Applicable	Missing	Deficient	Adequate	Exemplary	5	5	Section 3 of report
3.6	Is there a graphical representation of the modeler's conceptualization?	Not Applicable	Missing	Deficient	Adequate	Exemplary	3	5	Figure 2; does not include flow directions, magnitudes, or history
3.7	Is the conceptual model unnecessarily simple			Yes	Maybe	No	5	5	-
3.8	Is the conceptual model unnecessarily complex			Yes	Maybe	No	5	5	-
3.9	If any possibly key process is missing, is the justification adequate?	Not Applicable	Missing	Deficient	Adequate	Exemplary	0	0	No possibly missing key process identified
3.10	Are limitations and uncertainties described	Not Applicable		No	Maybe	Yes	4	5	Section 7.3 of report. However, model limitations and uncertainty in predictions not addressed specifically.

<b>Q.</b>	<b>QUESTION</b>	<b>Not Applicable or Unknown</b>	<b>Score 0</b>	<b>Score 1</b>	<b>Score 3</b>	<b>Score 5</b>	<b>Score</b>	<b>Max. Score (0 or 5)</b>	<b>COMMENT</b>
3.11	Has the conceptual model been reviewed independently		Unknown	No	Maybe	Yes	5	5	Yes, by USGS, GeoTrans, URS and others
<b>3.</b>	<b>TOTAL SCORE</b>						<b>36</b>	<b>40</b>	

# **MODEL REVIEW: 4. MODEL DESIGN**

Q.	QUESTION	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0 or 5)	COMMENT
4.1	Is the choice of mathematical model appropriate (analytical / numerical)			No	Maybe	<b>Yes</b>	5	5	MODFLOW 2000, MODPATH, MT3DMS
4.2	Is the spatial extent of the model appropriate			No	Maybe	<b>Yes</b>	5	5	Covers entire plume and zone of pumping and injection effects
4.3	Is the spatial discretization scale appropriate			No	Maybe	<b>Yes</b>	5	5	
4.4	Is the number of model layers justified			No	Maybe	<b>Yes</b>	5	5	There may be more layers than necessary
4.5	Is steady state simulated		Missing	Deficient	Adequate	<b>Exemplary</b>	5	5	-
4.6	Is transient behavior simulated		Missing	Deficient	<b>Adequate</b>	Exemplary	3	5	Extraction simulated but drawdown comparisons not presented (just reported in general)
4.7	Is the stress period reasonable		Missing	No	Maybe	<b>Yes</b>	5	5	Establishment of Depot to 50 years into future (1942 – 2053)
4.8	Is the number of time steps per stress period justified		Missing	Deficient	Adequate	<b>Exemplary</b>	5	5	Time steps in stress period defined by Courant number criterion
4.9	Are the applied boundary conditions plausible and unrestrictive		Missing	Deficient	<b>Adequate</b>	Exemplary	3	5	Flow boundary conditions general head or no flow, transport boundary conditions combine realistic timing with estimated concentrations. General-head boundaries may need to be transient.
4.10	Are boundary condition locations consistent with the model grid configuration		Missing	No	Maybe	<b>Yes</b>	5	5	-
4.11	Are the initial conditions defensible		Missing	Deficient	Adequate	<b>Exemplary</b>	5	5	Pre-pumping heads, zero TCE concentrations

<b>Q.</b>	<b>QUESTION</b>	<b>Not Applicable or Unknown</b>	<b>Score 0</b>	<b>Score 1</b>	<b>Score 3</b>	<b>Score 5</b>	<b>Score</b>	<b>Max. Score (0 or 5)</b>	<b>COMMENT</b>
4.12	Is it clear what software has been selected		Missing	No	Maybe	<b>Yes</b>	5	5	-
4.13	Is the software appropriate for the objectives of the study			No	Maybe	<b>Yes</b>	5	5	-
4.14	Is the software reputable			No	Maybe	<b>Yes</b>	5	5	Widely used and tested USGS and University of Alabama software
4.15	Is the software in common use and accessible to reviewers			No	Maybe	<b>Yes</b>	5	5	-
4.16	How detailed is the rainfall recharge algorithm	<b>Not Applicable</b>	Missing	Deficient	Adequate	Exemplary	0	0	Infiltration minimal
<b>4.</b>	<b>TOTAL SCORE</b>						<b>71</b>	<b>75</b>	

## MODEL REVIEW: 5. CALIBRATION

Q.	QUESTION	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0 or 5)	COMMENT
5.1	Is sufficient data available for spatial calibration		Unknown	No	Maybe	<b>Yes</b>	5	5	-
5.2	Is sufficient data available for temporal calibration		Unknown	No	Maybe	<b>Yes</b>	5	5	-
5.3	Does the model claim to be adequately calibrated for the purpose of the study		Missing	No	Maybe	<b>Yes</b>	5	5	-
5.4	Are calibration difficulties acknowledged	Not Applicable	Missing	Deficient	Adequate	<b>Exemplary</b>	5	5	Sections 7.1 and 7.3 primarily
5.5	Is it clear whether calibration is automated or trial- and- error		Missing	No		<b>Yes</b>	5	5	Trial-and-error
5.6	Is there sufficient evidence provided for model calibration		Missing	Deficient	<b>Adequate</b>	Exemplary	3	5	Transport calibration specifics not provided
5.7	Is the model sufficiently calibrated against spatial observations		Missing	Deficient	<b>Adequate</b>	<b>Exemplary</b>	4	5	Yes – flow Yes – main plume No – NEB plume
5.8	Is the model sufficiently calibrated against temporal observations		Missing	Deficient	<b>Adequate</b>	Exemplary	3	5	Downward trends in main plume modeled, but downward trends in NEB plume not modeled.
5.9	Are parts of the model well calibrated		Unknown	No	Maybe	<b>Yes</b>	5	5	Particularly flow under pumping conditions
5.10	Are parts of the model poorly calibrated		Unknown	Yes	<b>Maybe</b>	No	3	5	NEB plume TCE
5.11	Is the model calibrated to data from different hydrological regimes		Unknown	No	Maybe	<b>Yes</b>	5	5	Pre and post pumping
5.12	Are calibrated parameter distributions and ranges plausible		Missing	No	<b>Maybe</b>	<b>Yes</b>	4	5	Potentially re-evaluate hydraulic conductivities of southern alluvium and NE northern alluvium

<b>Q.</b>	<b>QUESTION</b>	<b>Not Applicable or Unknown</b>	<b>Score 0</b>	<b>Score 1</b>	<b>Score 3</b>	<b>Score 5</b>	<b>Score</b>	<b>Max. Score (0 or 5)</b>	<b>COMMENT</b>
5.13	Is a calibration statistic reported	Not Applicable	Missing	No	<b>Some</b>	Yes	3	5	Yes – flow No - transport
5.14	Does the calibration statistic satisfy agreed performance criteria	<b>Not Applicable</b>	Missing	Deficient	Adequate	Exemplary	0	0	Performance criteria no established
5.15	Are there good reasons for not meeting agreed performance criteria	<b>Not Applicable</b>	Missing	Deficient	Adequate	Exemplary	0	0	See above
<b>5.</b>	<b>TOTAL SCORE</b>						<b>55</b>	<b>65</b>	

# **MODEL REVIEW: 6. VERIFICATION**

Q.	QUESTION	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0 or 5)	COMMENT
6.1	Has some data been reserved for a verification exercise		Missing	No	Maybe	Yes	3	5	Comparison to pre-pumping heads (not detailed in report) might form partial (limited data) flow verification. NOT test results will provide further data.
6.2	Is the reserved data set an extension of the time period	Not Applicable	Missing	No	Maybe	Yes	0	0	-
6.3	Is the reserved dataset a suite of hydrographs not on the representative list	Not Applicable	Missing	No	Maybe	Yes	0	0	-
6.4	Is the volume of reserved data sufficient to establish verification	Not Applicable	Unknown	No	Maybe	Yes	0	0	-
6.5	Does the model claim to be verified		Missing	No	Maybe	Yes	1	5	-
6.6	Is there sufficient evidence provided for model verification	Not Applicable	Missing	Deficient	Adequate	Exemplary	0	0	-
6.7	Are parts of the model well verified	Not Applicable	Unknown	No	Maybe	Yes	0	0	-
6.8	Are parts of the model poorly verified	Not Applicable	Unknown	Yes	Maybe	No	0	0	-
6.9	Is the reserved dataset from a different hydrological regime	Not Applicable	Unknown	No	Maybe	Yes	0	0	-
6.10	Does the reserved dataset include stresses consistent with the prediction scenarios	Not Applicable	Unknown	No	Maybe	Yes	0	0	-

Q.	QUESTION	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0 or 5)	COMMENT
6.11	Are there good reasons for an unsatisfactory verification	Not Applicable	Missing	Deficient	Adequate	Exemplary	0	0	-
6.	TOTAL SCORE						4	10	

# MODEL REVIEW: 7. PREDICTION

Q.	QUESTION	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0 or 5)	COMMENT
7.1	Is prediction made for steady state conditions		Missing	No	Maybe	Yes	5	5	Post-pumping flow
7.2	Is prediction made for transient conditions		Missing	No	Maybe	Yes	4	5	Transport, but not flow
7.3	Are the assumed stresses reasonable		Missing	Deficient	Adequate	Exemplary	3	5	Transient flow predictions are warranted
7.4	Is the time horizon for prediction comparable with the length of the calibration / verification period		Missing	No	Maybe	Yes	5	5	50 years prediction versus 60 years calibration
7.5	Have multiple scenarios been run for climate variability	Not Applicable	Missing	Deficient	Adequate	Exemplary	0	0	Variations in Great Salt Lake level might have a minor effect
7.6	Have multiple scenarios been run for operational alternatives	Not Applicable	Missing	Deficient	Adequate	Exemplary	0	0	Alternate future sources and future pumping or injection rates were not considered. This was perhaps not within scope.
7.7	Are model predictions made at scales consistent with model space and time scales		Missing	No	Maybe	Yes	5	5	
7.8	Are the model predictions plausible			No	Maybe	Yes	5	5	
7.9	Are model predictions likely to be impacted by constraining boundary conditions		Unknown	Yes	Maybe	No	3	5	TCE source assumptions determine conclusions about efficacy of future pumping
7.10	If boundary conditions affect the predictions are the predictions defensible		Unknown	No	Maybe	Yes	3	5	Predictions less defensible for NEB plume
7.	TOTAL SCORE						34	40	

# **MODEL REVIEW: 8. SENSITIVITY ANALYSIS**

Q.	QUESTION	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0 or 5)	COMMENT
8.1	Is there discussion of qualitative sensitivities found during calibration	Not Applicable	Missing	Deficient	Adequate	<b>Exemplary</b>	5	5	Fault hydraulic conductivity, Source assumptions. Further sensitivity analyses are proposed.
8.2	Has a post- calibration sensitivity analysis been performed		<b>Missing</b>	Deficient	Adequate	Exemplary	0	5	
8.3	Is the sensitivity analysis sufficiently intensive for key parameters	Not Applicable	<b>Missing</b>	Deficient	Adequate	Exemplary	0	5	
8.4	Is there a graphical presentation of sensitivity behavior	Not Applicable	<b>Missing</b>	Deficient	Adequate	Exemplary	0	5	
8.5	Are sensitivities classified as Type I to Type IV	Not Applicable	<b>Missing</b>	No		Yes	0	5	
8.6	Has a Type IV sensitivity been recognized	Not Applicable	<b>Missing</b>	Yes	Maybe	No	0	5	
8.7	Is there a list of ranked sensitivity coefficients	Not Applicable	<b>Missing</b>	Deficient	Adequate	Exemplary	0	5	
8.8	Are sensitivity results used to qualify the reliability of model calibration	Not Applicable	<b>Missing</b>	Deficient	Adequate	Exemplary	0	5	
8.9	Are sensitivity results used to qualify the accuracy of model prediction	Not Applicable	<b>Missing</b>	Deficient	Adequate	Exemplary	0	5	
<b>8.</b>	<b>TOTAL SCORE</b>						<b>5</b>	<b>45</b>	

# **MODEL REVIEW: 9. UNCERTAINTY ANALYSIS**

Q.	QUESTION	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0 or 5)	COMMENT
9.1	Is the uncertainty in aquifer properties acknowledged or described/ quantified		Missing	Deficient	Adequate	<b>Exemplary</b>	5	5	
9.2	Are uncertainties in stress datasets acknowledged or described/ quantified	Not Applicable	Missing	Deficient	Adequate	<b>Exemplary</b>	5	5	
9.3	Are uncertainties in observation data acknowledged or described/ quantified	Not Applicable	Missing	Deficient	Adequate	<b>Exemplary</b>	5	5	Appropriate averaging used to reduce uncertainty
9.4	Are uncertainties in predicted outcomes acknowledged or described/ quantified	Not Applicable	Missing	Deficient	Adequate	<b>Exemplary</b>	5	5	
9.5	If required by the project brief is uncertainty quantified in any way	<b>Not Applicable</b>	Missing	No	Maybe	Yes	0	0	Brief not reviewed
9.6	If uncertainty has been quantified has an acceptable method been used	<b>Not Applicable</b>	Missing	Deficient	Adequate	Exemplary	0	0	See above
9.7	If uncertainty has been quantified how extensive is the analysis	<b>Not Applicable</b>	Missing	Deficient	Adequate	Exemplary	0	0	See above
<b>9.</b>	<b>TOTAL SCORE</b>						<b>20</b>	<b>20</b>	

### SUMMARY OF MODEL APPRAISAL

Area	QUESTION	Actual Score	Max possible Score
1	Report	60	73
2	Data Analysis	64	75
3	Conceptualization	36	40
4	Model Design	71	75
5	Calibration	55	65
6	Verification	4	10
7	Prediction	34	40
8	Sensitivity Analysis	5	45
9	Uncertainty Analysis	20	20
	<b>TOTAL SCORE</b>	<b>349</b>	<b>443</b>



## APPENDIX B: MINOR REPORT COMMENTS

1. **Section 3.1.2, Additional Fault Zones, page 11, 3<sup>rd</sup> paragraph:** In the last sentence of the paragraph, suggest change the word “created” to “hypothesized.”
2. **Section 3.3, Contaminant Sources, page 14, end of section:** Note that potential additional sources include:

Buildings 600, 606, 607, 611, 614, 620, and 637 (Kleinfelder 2002).

Old Tooele city landfill, vicinity of building 691 and well E-15, Bolinder property (Parsons 2003).
3. **Section 3.4, page 15, 4<sup>th</sup> paragraph:** Kd values used in model were not specified.
4. **Section 4.2.3.1, Recharge, page 18, 2<sup>nd</sup> paragraph:** Conversion errors: Change the following numbers 0.0022 in/yr to “0.88 in/yr” and 0.0012 in/yr to “0.44 in/yr,” 0.0012 in/yr to “0.44 in/yr.”
5. **Section 4.2.3.1, Recharge, page 18, 3<sup>rd</sup> paragraph:** Since recharge is only about 1 percent of the total inflows to the model this result is expected
6. **Section 5.2.3 Adjustments to TCE Source Concentrations, page 26, Table 4:** Recharge concentration for IWL Ditch (1965 – 1987) should be 13,000 µg/L.
7. **Section 5.2.4, Adjustments to Porosity and Sorption Coefficient, page 27, 3<sup>rd</sup> paragraph:** Last paragraph: Kd and bulk density in zone 14 of model is zero.
8. **Figures 2 and 3, pages 41 and 42:** On the legend the Old Industrial Waste Lagoon is not shown on the figures.
9. **Figure 4, page 43:** Figure does not include injection and extraction wells in legend.
10. **Figure 5, page 44:** Figure does not show zero flow on SW boundary.
11. **Figure 7, page 46:** Color is missing on figure for the Far North Alluvium. Please provide hydraulic values for each color on this and subsequent figures. Note that hydraulic conductivity zones in model differ slightly from those shown in Figures 7 to 16.
12. **Figure 16, page 55:** Please provide infiltration rates in the legend.
13. **Figure 20, page 59:** What a great figure!
14. **Appendix B, page B-3, last sentence of section:** Table 2 should be Table 1.

